Remediation Technology Collaboration Development – A Compendium

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Acronyms

A&E	Architecture/Engineering firms
AOC	Area of concern
AOI	Area of Investigation
CERCLA	Comprehensive Environmental Response, Compensation, & Liability Act
CHEMOX	Chemical oxidation
COC	Contaminants of concern
CF/CFs	Component Facility
CTC	Carbon tetrachloride
CY	Calendar Year
DCA	Dichloroethane
DCE	Dichloroethene
DNAPL	Dense non-aqueous phase liquid
DMA	Dimethylamine
EMD	Environmental Management Division
FDEP	Florida Department of Environmental Protection
FY	Fiscal year
GAC	Granular activated carbon
gpm	Gallons per minute
HC	Hydrocarbons
ITB	International Trade Bridge
LNAPL	Light non-aqueous phase liquid
LOC	Location of concern
LTM	Long term monitoring
MCL	Maximum contaminant level
mg/L	milligrams per liter
MEW	Middlefield-Ellis-Whisman
MPITS	Mid-Plume Interception Treatment System
MW	Monitoring well
NAS	Naval Air Station
NASA	National Aeronautics and Space Administration
NDMA	N-nitrosodimethylamine
NETS	NASA Environmental Tracking System
NPDES	National Pollutant Discharge Elimination System
OU	Operable Unit
PAH	Polycyclic aromatic hydrocarbon
PBC	Performance-Based Contracting
PCE	Tetrachloroethylene
PCB	Polychlorinated biphenyl
PCC	Post Closure Care
PCT	Polychlorinated terphenyls
PFTS	Plume Front Treatment System
ppb	Parts per billion
ppm	Parts per million
P&T	Pump and treat
RBC	Risk-Based Closure
RFI	RCRA Facility Investigation
ROD	Record of Decision

RCRA	Resource Conservation & Recovery Act
RPM	Remediation Project Manager
RTCD	Remediation Technology Collaboration Development
SVE	Soil vapor extraction
SVOC	Semi-volatile organic compound
SWMU	Solid waste management unit
TCE	Trichloroethylene
TPHg	Total petroleum hydrocarbons as gasoline
TCA	Trichloroethane
ug/L	micrograms per liter
UAV	Unmanned Aerial Vehicle
USEPA	United States Environmental Protection Agency
UST	Underground storage tank
UV	Ultra-violet
VC	Vinyl chloride
VOC	Volatile organic compound

EXECUTIVE SUMMARY

International Trade Bridge, Inc. (ITB), under the Remediation Technology Collaboration Development Task Order (RTCD TO), was tasked to provide Environmental Compliance and Restoration (ECR) Program support, in the form of an Independent Technical Entity, to the National Aeronautics and Space Administration (NASA).

ITB supported NASA in executing and managing the RTCD TO from May 1, 2010 to February 28, 2017. The RTCD task order's goals were to enhance NASA's capability to target reductions in the long-term liabilities associated with NASA's most challenging remediation sites. ITB accomplished this by:

- Identifying existing remediation processes and conditions,
- Researching site-specific alternative technologies and/or process improvement opportunities, and
- Developing pilot studies and demonstration projects for implementation

Approach

The initial RTCD task order focused on information gathering, engagement with NASA Environmental Management Division (EMD) Program Leads and Liaisons and NASA's Remediation Project Managers (RPM) to understand current and past remediation technologies, establish liability drivers, identify potential partnerships and propose alternative technologies. Ongoing work included steps to identify technologies, locations and stakeholders, implement technology demonstrations, share results and monitor activities. Opportunities associated with the long-term environmental liability, which includes both cost and site clean-up timelines, were defined and considered as potential projects.

This Compendium Report documents the entirety of the RTCD "program" and is organized to provide an overview while highlighting the projects and significant ideas that were generated. Areas of prime consideration were cleanup technologies, site characterization/assessments and process improvements (e.g. optimization). Throughout this RTCD effort, ITB maintained an unbiased posture for assessment of the conditions at each NASA Center and Component Facility.

RTCD Initiatives

- Risk-Based Closure – the next step for Agency-wide "low hanging fruit" opportunities (on-going)
- Numerous Technology Demonstrations and Pilot Studies at Stennis Space Center (SSC), including Performance-Based Remediation (PBR)
- Real-Time Monitoring (includes visualization), Detection and Mitigation for Vapor Intrusion (VI) of Trichloroethylene (TCE) – research and development is on-going
- Enhancement of the Ultraviolet (UV) Photochemical Degradation system at WSTF
- Sustainable energy sources to support remediation technologies (on-going)
- Innovative Site Characterization Technology – Hyperspectral Imaging (Proof of Concept completed successfully, research and development is on-going)
- NASA Environmental Tracking System (NETS) ECR Technologies Module (on-going)
- High Resolution Site Characterization (HRSC) including real-time quantitative measurement of TCE in groundwater and web-based visualization of data
- Assessment and treatment of soil and groundwater using Horizontal Direction Drilling (HDD)

RTCD Successes:

- RTCD Phase I task was successful in that the summarization of NASA's environmental efforts enabled ITB to gain a clear understanding of the clean-up activities throughout the Agency
    - Established the capability to provide significant reductions in demonstration costs to NASA
    - Initiatives provided throughout the RTCD task periods went above and beyond the initial UEL-driven requirements
- Researched fifteen (15) site remediation/characterization technologies in depth and more than fifty (50) others to a lesser degree. This resulted in:
    - Initiation of seven (7) remediation technology pilot studies/demonstrations, three of which are expected to achieve site closure in the near-term.
    - Nearly fifty percent (50%) of the project costs were provided in-kind by participants outside of the Agency (ITB successfully negotiated in-kind services, materials and equipment)
- NETS ECR Technologies Module Go-Live Date – September 2015
    - Streamlines the process for end-of-year updating of the Annual Summary of Remediation Technologies at NASA database. What took months to complete previously is now a five to fifteen minute task for each of the RPMs.
    - Enabled the ICS risk analysis of 177 cleanup sites in less than two weeks by one engineer
- Implemented NASA's first PBR as an alternative site closure strategy (sets a fixed ceiling on "cost-to-closure")
- Agency-wide analysis of Industrial Control Systems (ICS) that support environmental cleanup operations
    - NASA's first comprehensive cyber-security assessment of ICS
    - ITB served as the technical lead and project integrator between NASA's Information Technology (IT), Operational Technology (OT) and the remediation communities.
- Identified and provided numerous informative and engaging topics for presentation by Subject Matter Experts (SME) at several RPM Workshops and webinars.

RTCD Highlights:

Technology Demonstrations and Pilot Studies at SSC

ITB worked with SSC and technology vendors to demonstrate several remediation technologies. These included:

- Risk-Based Closure
- Performance-Based Contracting
- In-situ Real-Time Monitoring of TCE in Groundwater
- In-situ Chemical Oxidation (ISCO) of TCE in Groundwater
- ISCO of Contaminated Soils using Horizontal Direction Drilling (HDD) for Injection

Process Improvements

ITB identified and evaluated a number of process improvements that can reduce costs and time to cleanup. These included an approach to risk-based closure and site-specific evaluations and recommendations for SSC. ITB also coordinated a performance based contracting (PBC) approach that requires the subcontractor to essentially "take ownership" of site cleanup and closure.

Agency-wide Analysis of Industrial Control Systems that Support Cleanup Operations

ITB conducted an Agency-wide analysis of Industrial Control Systems (ICS) that support environmental cleanup operations. The primary objective of this study was to identify and analyze the vulnerabilities (i.e. cyber risks) of NASA Centers and CFs related to all groundwater treatment systems and supporting infrastructure that utilize ICS.

NETS ECR Technologies Module

Beginning with the initial RTCD Task Order, ITB developed a summary of the past, current and planned remediation technologies employed at or expected to be employed at the NASA Centers and Component Facility (CF) sites. This overview helped NASA and ITB gain a better understanding of the clean-up activities throughout the Agency and set the stage for effective technology and strategy improvement recommendations regarding environmental remediation. This summary proved to be a useful tool (Excel file), and ITB evolved the spreadsheet into a web interface supported online component (ECR Technologies Module) of the existing NETS database program. In addition, the NETS Technologies database was instrumental and served as an information focal point for the recent ICS sub-task, thereby saving a considerable amount of time in the process.

NASA Goddard Space Flight Center TCE Groundwater Plume

ITB supported the RPM at GSFC by conducting an assessment of their TCE plume with the objective of providing data-supported suggestions and recommendations for alternative or potential enhancements to existing remediation activities and strategies. ITB identified several risk mitigation approaches and recommended some additional site characterization work.

Innovative Site Characterization Technologies – Hyperspectral Imaging

The capability exists for conducting environmental assessments of TCE in groundwater using Hyperspectral Imaging (HSI), primarily through vegetative markers. Technologies and projects included:

- Airborne Hyperspectral Imaging Systems
- Unmanned Aerial Vehicles (UAV) Platform discussions
- Agency-wide Plant Species Database to Support Hyperspectral Imaging
- Hyperspectral project opportunity at Goddard Space Flight Center (GSFC)

Vapor Intrusion and Mitigation

In 2011, the U.S. Environmental Protection Agency (EPA) released its final health assessment (Assessment) for TCE. New enforceable standards are years away, but it is likely that the revised TCE values will be used on an ad hoc basis in regional EPA offices. TCE in groundwater at NASA sites may face additional cleanup requirements based on its potential for vapor intrusion and additional public exposure. ITB reviewed the potential for vapor intrusion of TCE to pose risks for NASA's remediation program and documented technologies for detection and mitigation.

Recommendations/Issues/Concerns

- Conduct an Agency-wide analysis of sites where Risk-Based Closure can be an effective alternative
- New V.I. acute exposure limit to TCE are coming to fruition. Risks associated with TCE vapor intrusion into NASA buildings, particularly at ARC, JPL and MSFC, are confirmed issues. Also, there's a potential cost risk if thresholds are exceeded.
  - May require continuous real-time monitoring of indoor air.
  - Evacuations of buildings if thresholds are exceeded…
  - Several states including California and New Jersey are following the EPA Region 9's lead and have begun using or are considering developing short term exposure limits for TCE.
- How to convey the importance of attending conferences and workshops?
  - Successes: Collaborative Partners for RTCD pilot studies were met at conferences etc.
  - Convinced: Attending remediation-specific conferences are essential
- Determine/assess the potential effects of catastrophic events on existing clean-up sites (consider lessons learned from Hurricanes Katrina, Matthew and Harvey, for example). It was also noted that these assessments had not been conducted from an Agency perspective/initiative.

Summary:

Several factors became known initially and throughout this task: 1) Every NASA Center/CF is under some form of remediation, 2) contamination at many of the sites is extensive and widespread, 3) clean-up would require a considerable amount of resources, and 4) various technologies either have been used, are in use or have been considered already. In addition, based on the contaminants involved, their concentrations and each site's unique geology and hydrogeology, successful use of remediation technologies resulting in closure, is generally considered to be site specific.

During review of NASA's remediation program, ITB observed a recurring theme (which remains to this day); additional site characterization and updated conceptual site models (CSMs) are required before realistic expectations of remediation effectiveness can be determined. In many cases, remedial actions have failed due to inadequate understanding of the size and location of contaminant sources and its effects on groundwater. ITB has learned, and conveyed, that proper, complete, and recent site characterization is just as crucial to site cleanup success as selecting the appropriate remedial technology. In addition:

- Remediation strategies for older spill sites should always take into account that significant contaminant mass has diffused into low permeability zones and will act as a long term source that is difficult to address.
- The success of in situ technology depends mostly on the effectiveness of delivery (contact with contaminant is required).
- The consensus among experts seems to be that TCE is a particularly difficult contaminant to clean-up (i.e. to drinking water standards) and alternative endpoints to active remediation should be considered (long term monitoring and institutional controls may be required).
- Pump and treat should be considered a containment strategy, not a remediation strategy.

1. Introduction

During its multi-year period of performance, the RTCD task order's initial goals were to enhance the capability to specifically target reductions in the long-term liabilities associated with NASA's most challenging remediation sites. This was accomplished by identifying existing remediation processes and conditions, researching site-specific technologies (both past and present) while simultaneously looking for parallel situations where these technologies could be applied. In addition, the most promising of these solutions were developed from comprehensive research and bench studies into pilot studies or demonstration projects, which contributed significantly to the success of the RTCD "program." Examples include:

1. Surveyed all NASA Centers and CFs to understand current and past remediation technologies.
2. Researched each cleanup site and their conditions to identify the liability drivers for NASA in terms of cost and technical difficulty.
3. Formed a comprehensive baseline of site remediation processes/conditions to serve as a reference point and path-forward guide for applying liability-reducing opportunities.
4. Researched existing and emerging technologies, processes and strategies that could significantly reduce the environmental liability in terms of cost and schedule.
5. Collaborated with potential partners who experienced similar situations i.e. leverage resources and ideas to develop cost-sharing opportunities for technology implementation.
6. Identified sites where the use of alternative technologies offered better economic outcomes (life-cycle costs between in-situ remediation technologies vs. long-term pump and treat, for example)
7. Evolved and managed the RTCD task order and its renewals into a program-like operation i.e. many activities continued year after year.
8. ITB initiatives regarding RTCD went above and beyond the initial UEL-driven requirements.

NASA maintains a wide range of facilities across the U.S. (Table 1). Unfortunately, historical practices resulted in soil and groundwater contamination requiring NASA to remediate appropriately. The RTCD task was established to support NASA, along with its Centers and CFs, with environmental remediation at these locations.

NASA Centers
Armstrong Flight Research Center (AFRC) – Edwards Air Force Base, CA
Ames Research Center (ARC) – Mountain View, CA
Glenn Research Center (GRC) at Lewis Field – Cleveland, OH
Goddard Space Flight Center (GSFC) – Greenbelt, MD
Jet Propulsion Laboratory (JPL) – Pasadena, CA
Johnson Space Center (JSC) – Houston, TX
Kennedy Space Center (KSC) – Merritt Island, FL
Langley Research Center (LaRC) – Hampton, VA
Marshall Space Flight Center (MSFC) – Huntsville, AL
Stennis Space Center (SSC) – Hancock County, MS
NASA Component Facilities
Plum Brook Station (PBS - Aligns to GRC) – Sandusky, OH
Wallops Flight Facility (WFF - Aligns to GSFC) – Chincoteague Island, VA
White Sands Test Facility (WSTF - Aligns to JSC) – Las Cruces, NM
Michoud Assembly Facility (MAF - Aligns to MSFC) – New Orleans, LA
Santa Susana Field Laboratory (SSFL Aligns to MSFC) – Simi Valley, CA

Table 1 NASA Centers and CFs

The purpose of this Compendium Report is to document the entirety of the RTCD program as an historical reference, from May 1, 2010 to February 28, 2017. It is organized to provide an overview for the RTCD program while highlighting the projects and ideas that were generated as part of the RTCD Task Orders. Areas of prime consideration were cleanup technologies, site characterization/assessments and process improvements e.g. employment of long-term monitoring and Green Remediation[1] strategies.

Typically, a Compendium is *a referenced compilation of a significant body of scientific research and technical writings that succinctly summarizes key studies and other findings relevant to a particular area of work*, and this paper follows that same format. In other words, readers who want to delve deeper can consult the reports and other documents that are referenced within.

2. RTCD Approach and Management Processes

Opportunities associated with the long-term environmental liability, which includes both cost and site clean-up timelines, were defined and considered as potential projects during the course of this task order. Demonstration of support for technical impracticability (TI) waivers, where warranted, were pursued as well. As clean-up sites are generally site-specific in regards to contaminants of concern (COCs), geology, hydrology, lithology (i.e. Hydrogeology) etc., these opportunities typically targeted one NASA site. However, similar conditions can exist at other sites, both locally and globally. As such, ITB's initial approaches for identifying site-specific opportunities were collaborative in nature by conferring with NASA's Remediation Project Managers (RPMs) and their Liaisons at NASA Headquarters (HQ). In addition, ITB viewed NASA Headquarters, Environmental Management Division (EMD), as an integral member of its team/s.

Throughout this RTCD effort, ITB maintained an unbiased posture for assessment of the conditions at each NASA Center and Component Facility. In other words, ITB did not have any responsibility for site remediation requirements at NASA, nor provided any remediation services at NASA, and therefore was able to perform with complete impartiality.

ITB's methods for conducting technology research consists of searching through electronic information resources (e.g., internet, various technical library resources, etc.), both domestic and international, from peer-reviewed reports, and to a lesser extent non-peer reviewed reports. In addition, proceedings from remediation-focus conferences are other significant resources of information as well.

Another purpose of this research is to stimulate ideas for developing projects that may include demonstration and validation of alternative technologies prior to implementation. Such projects may include application of cost reducing renewable energy technologies to remediation systems.

Project Approach (initial):

1. Preliminary information gathering.
2. Interview NASA EMD Environmental Compliance & Restoration (ECR) Program Leads and Liaisons.
3. Survey NASA Centers and CFs to understand current and past remediation technologies.
4. Establish liability drivers by expressing site remediation performance in terms of cost and technical difficulty.
5. Prepare a findings report describing each Center and CF's current conditions and technologies (in-use and proposed).
6. Identify potential partnerships.
7. Propose alternative technologies.

[1] Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites - EPA

Project Approach (recurring)

- Identify technologies and locations
- Identify stakeholders
- Implement technology demonstration
- Share result(s)
- Monitor previous and on-going RTCD activities

Clean-up site prioritization considerations (cost and risk score)

- Cleanups are prioritized by EMD to ensure that the highest priority liabilities are addressed first in order to protect human health, the environment and preserve natural resources for future missions.
- "Low-hanging fruit" opportunities, which were often in the form of assistance requests from the RPMs.

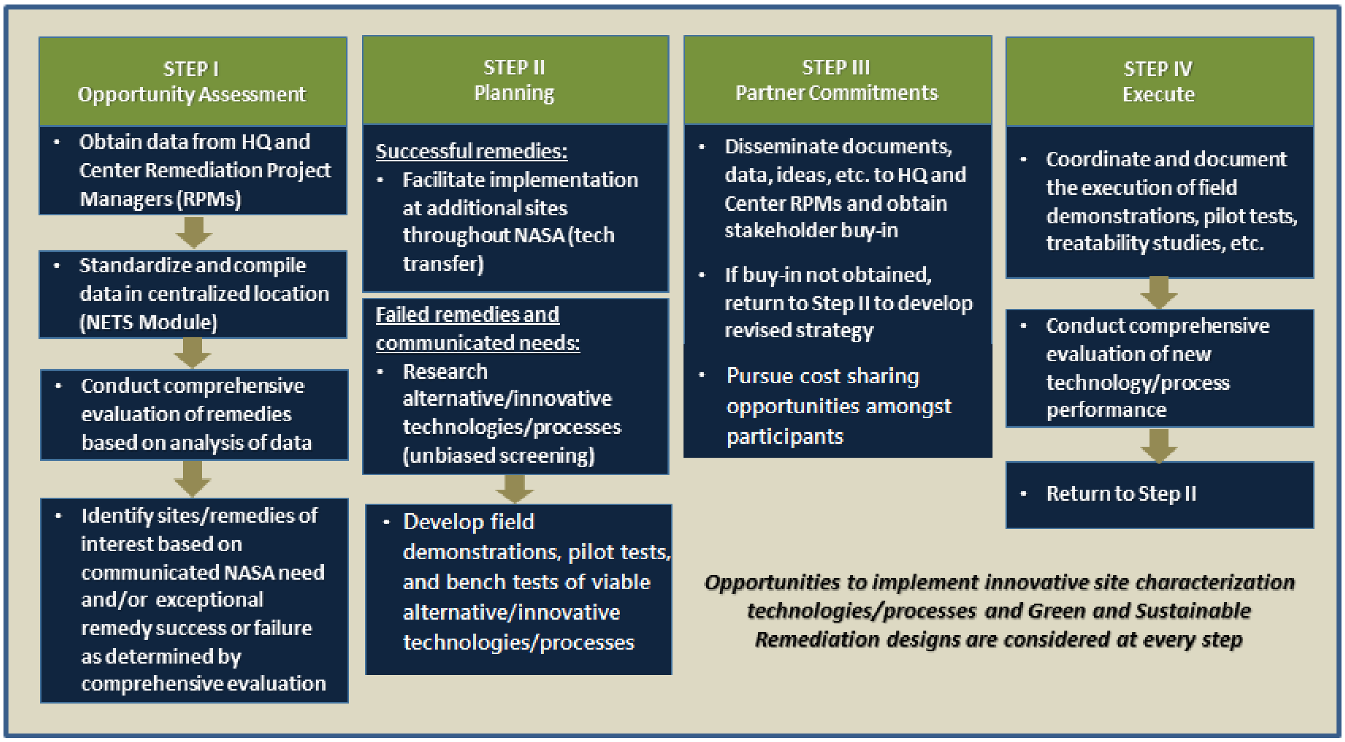

Figure 1 RTCD Project Development Process – Defined "on paper" during 2015

The above graphic depicts the project development process that was developed by ITB for the RTCD Task Order. This process guided the RTCD Program since its inception, and served as the basis for project development.

For thoroughness, the scope of ITB's research into remediation alternatives included technologies of varying degrees of maturity, and available both nationally and internationally. General areas of prime consideration included cleanup technologies, employment of renewable energy systems (green remediation), and long-term monitoring. These categories are applicable to all NASA sites.

As ITB began screening and down-selecting the existing and emerging technologies, two feasibility factors served as primary considerations, technical and cost. One measure of technical feasibility was adopted from NASA and the DOD, the Technology Readiness Level[2] (TRL), process. By using TRL, the technologies selected for consideration can be weighted to high, medium, or low in regards to a particular site or contaminant of concern. In many instances, the technology was a high TRL, but needed to be pilot-tested for the exact site conditions to validate suitability and benefits.

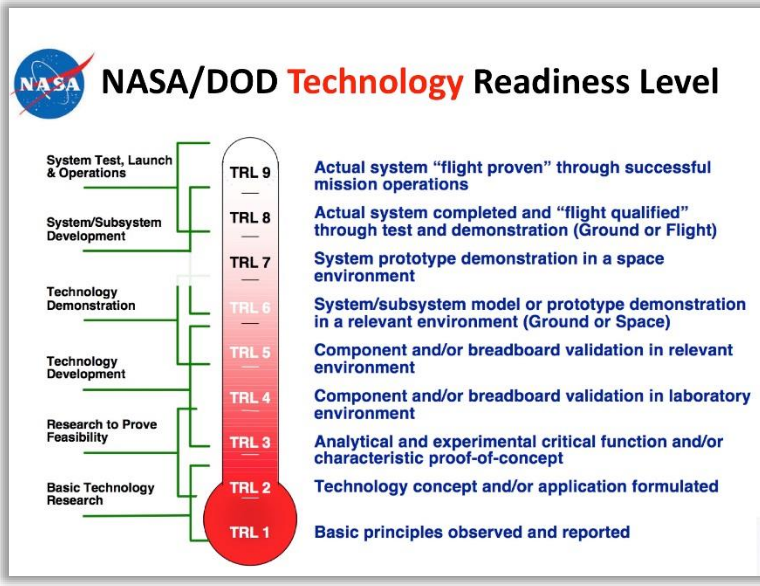

Figure 2 TRL Chart used by NASA and the DOD

Another measure of technical feasibility is technical acceptability. This includes the extent to which the technology has been studied and critiqued by subject matter experts and the like, including test result data from previous technology demonstrations. Just as important, another measure of acceptability is the extent to which environmental regulators have weighed in regarding their Agency's known or likely acceptance of the technology.

Cost is another critical factor during the technology screening process. Based on best available data, ITB compared projected life cycle costs of the alternative technology(ies) to that of the current remediation systems. Life cycle costs include system-operating costs over the entire project and/or treatment lifetime. For these reasons, alternative technologies that meet cleanup levels in a shorter period of time could have overall cost advantages when compared to an existing system that takes longer to meet the established cleanup goal.

> "Recommendation of technically and financially feasible technologies and potential demonstration partners can reduce concerns, hasten implementation, and reduce NASA's long-term cleanup liabilities."

Importance of Partners and Stakeholders (costs sharing)

An important element of ITB's approach to project development involved determining what the objective of the project would be, along with sources of funding. Ultimately, the selection of alternative technology(ies) for evaluation was determined by consensus of the project's stakeholders—consensus which was often initiated and facilitated by ITB. To properly engage prospective team members and help define the goals of the proposed project, ITB frequently hosted teleconferences, and webinars as well. Participants in these meetings included representatives from NASA Centers and CFs, government agencies, and industry experts interested in the project of discussion.

[2] Technology Readiness Levels - NASA

Testing of a remedial technology (either at bench-scale or full-scale) is commonly required if no data is available to prove that the technology's performance is at least equal to the performance of the current system. Additionally, this is often precedes regulatory agencies' acceptance as well. In these cases, some type of funding - either direct (externally provided) or in-kind[3], is often secured beforehand. ITB pursued cost sharing methods for collaborative projects and worked with stakeholders to obtain funding commitments, generally from external sources. The following table provides examples of ITB's cost-sharing successes at SSC during the RTCD Task.

Demonstration or Project	POP	Direct (total) Cost	Cost to NASA	Cost Savings to NASA via In-Kind Contributions from Partners
In situ real-time measurement of TCE in groundwater (Area D)	9/11 - 11/11	$28,000	$0	($28,000)
In situ chemical oxidation of TCE in groundwater (Area G)	3/12 - 12/12	$184,300	$112,425	($71,875)
In situ bioremediation of TCE in groundwater (Area D)	8/13 - 6/14	$17,974	$0	($17,974)
HDD Installation of Multiport Sampling & Injection Well (Area B)	7/14 – 7/14	$32,500	$24,500	($8,000)
In Situ Chemical Oxidation of TCE in Groundwater using Horizontal Multiport Injection Well (Area B)	9/14 - Present	$64,750	$0	($64,750)
Risk-Based Closure – SSC Area D	Ongoing	$116,000 (Estimated)	$76,000 (Est)	($25,000)
TOTALS		**$443,524**	**$212,925**	**($215,599)**

Table 2 RTCD / SSC Cost Sharing

Some Centers utilize what EMD refers to as "resource sharing" to further their restoration efforts while also maximizing available resources. Resource sharing involves utilizing another agency's environmental restoration contract and contractors to accomplish NASA's restoration efforts. For example, Langley uses U.S. Navy contracts and contractors to perform the majority of restoration work at the Center. According to EMD officials, this type of effort allows NASA to complete restoration efforts more efficiently since the other agency has an existing contract and the work can be performed for NASA on a reimbursable basis.

[3] Contributed by project stakeholders at no cost to the rest of the team.

Project Development Objectives as it applied to RTCD (summary):

1. Down-selection of applicable technologies to the most promising alternatives
2. Identification of the technical requirements necessary to validate these alternatives
3. Determining appropriate cost sharing among affected programs and participants, and…
4. … obtaining funding commitments from project stakeholders

With that in mind, ITB developed and proposed collaborative projects, performed together with outside partners, for validation and application of technologies at NASA sites. In consultation with NASA EMD, ITB explored technical opportunities for development into active projects. Examples included:

- In-situ real-time monitoring of trichloroethylene (TCE) in groundwater
- In-situ chemical oxidation (ISCO) of TCE in groundwater
- ISCO of contaminated soils using horizontal direction drilling (HDD) for injection
- Agency-wide analysis of sites where risk-based closure (RBC) can be an effective alternative
- Determine the potential effects of climate change on existing clean-up sites
- Ultraviolet (UV) photochemical degradation enhancement
- Renewable energy sources to support remediation technologies
- Vapor intrusion detection and mitigation

Project Team Development

Identifying potential stakeholders was the basis for developing a project team, which became the focal point for determining performance-requirements and expectations. Because of the close interrelation between the technical and financial aspects of a project, ITB conducted the project's technical and business activities concurrently with all participants.

In addition, ITB researched potential partners for similar situations where resources could be leveraged to develop and/or deploy liability-reducing technologies. Subject matter experts and other interested parties were contacted via ITB's existing network of partners and organizations, such as:

- NASA's Principle Centers and Sustainability Officers
- Department of Defense (DoD)
  - U.S. Air Force Center for Engineering and the Environment
  - The U.S. Army's Defense Environmental Restoration Program
  - U.S. Army Corp of Engineers
  - U.S. Navy's Environmental Restoration Program
- NASA-C3P International Workshops on Environment and Energy, which involves many international organizations
  - European Space Agency (ESA)
  - European Environment Agency (EEA)
  - PBL Netherlands Environmental Assessment Agency
  - German Aerospace Center (DLR)
  - Centre National d'Etudes Spatiales (CNES) – France
- Industry

    - Geosyntec Consultants
    - Tetra Tech Inc.
    - ARCADIS (an international company)
    - AECOM
- Other government agencies and organizations
    - U.S. Environmental Protection Agency (USEPA)
    - U.S. Geological Survey (USGS)
    - California Department of Toxic Substances Control

Several of the above-mentioned groups and organizations, including many NASA Centers, have made considerable strides towards reducing risks by remediating contaminants within their environments. By parsing through information and research documents at their respective websites (e.g., NASA, DOD, DTIC, etc.), enough knowledge was gained by ITB to engage and contribute to discussions between interested parties. By using the collaboration techniques established and led by ITB, new teams were developed as needed, for site and/or technology-specific projects.

At times, and as part of ITB's role in facilitating project development, ITB technical staff traveled to NASA Centers for face-to-face project development meetings with Center/Component Facility RPMs.

3. Drivers that generated the RTCD Task Order

NASA maintains a wide range of facilities across the U.S. (see Table 1). Unfortunately, historical practices resulted in soil and groundwater contamination. Environmental regulations, executive orders and NASA policy require remediation of this contamination. For example:

- NASA Procedural Directives (NPDs) and NASA Procedural Requirements (NPRs)
    - NPR 8590.1A NASA Environmental Compliance and Restoration (ECR) Program
    - NPR 9260.1 Revenue, Unfunded Liabilities, and Other Liabilities
- Federal Laws
    - Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA)
    - Oil Pollution and Control Act of 1990 (OPA)
    - Resource Conservation and Recovery Act of 1976 (RCRA)
    - Toxic Substances Control Act of 1976 (TSCA)
- Executive Orders (EOs)
    - EO 12088 Federal Compliance with Pollution Control Standards
    - EO 12580 Superfund Implementation
    - EO 12898 Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations
    - EO 13016 Amendment to EO 12580 Concerning Exercise of Authority Under CERCLA Section 106

NASA faces a challenge in funding the large cost of soil and groundwater contamination at its Centers and CFs. Just estimating its unfunded environmental liability (UEL) is a challenge in itself. However, NASA continues to improve its process for UEL estimation. One area for improvement, identified in the FY 2009 OIG audit[4], focused on establishing and implementing an Agency-wide policy to capture cleanup costs for removing, containing,

[4] NASA's Most Serious Management and Performance Challenges (Nov 2009 – see page 7)
Environmental Liability Estimation (2009)

and/or disposing of hazardous waste from property or material associated with the permanent or temporary shutdown of a program.

Environmental Liability Estimation. Over the past several years, NASA has taken proactive measures to improve its financial statement preparation processes and oversight. As a result, this issue is no longer reported as a material weakness for FY 2009; however, NASA has challenges estimating its unfunded environmental liability (UEL). These challenges include establishing an Agency-wide policy and ensuring consistent implementation of the policy across the Agency.

NASA is obligated to remediate its soil and groundwater contamination, abide by agreements with the USEPA and state environmental protection agencies, protect human health and the environment, and use its resources in a cost-effective manner. The RTCD task addresses NASA's need to evaluate current approaches to remediation by identifying and implementing new and efficient remediation technologies across the agency.

Note; ITB received UEL guidance and direction from NASA EMD. As such, ITB was not an active participant in the UEL decision processes. However, the UELs served as an overarching influence throughout the RTCD program's period of performance.

> *Concern: "There are no decision making points to reevaluate technology or remedial action objectives."*
>
> *TEERM's collaborative strategy corrected this issue by, "Encouraging re-evaluation of remedial strategy if [existing strategies are] not making reasonable progress toward meeting remedial action objectives and cleanup levels."* [5]

Examples of risks that *induced* liabilities:

- Auditors have identified the estimation of NASA's Unfunded Environmental Liability as a "Reportable Condition" which is contributing to NASA being unable to obtain a clean audit of its Financial Statement
- NASA is actively working with the State of California on remediation at the Santa Susana Field Laboratory, where NASA manages 540 acres of the 2800-acre facility formerly used for Rocket Testing and nuclear power research by the Department of Energy. In September 2009, NASA declared the government land as excess to NASA's needs thereby generating strong interest from the public, as well as Congress, State, and local officials, for acquiring this property. In addition, a State Law[6] was enacted specifically for this facility, and soil cleanup alone could range between $55 and $180 Million
- New hazardous waste operating permit at WSTF includes strict deadlines for the completion of investigations and resulted in an increase of $5M per year for the next five years (as of 2015)
- EPA updates the trichloroethylene toxicity values which includes vapor intrusion

[5] NASA EMD/ITB PMR commentary – November 11, 2013

[6] California's Senate Bill 990 – Schwarzenegger, October 2007

4. RTCD History by Task Order

2010 Phase 1 (May 1, 2010 to December 31, 2010)

The purpose of RTCD TO was to establish the capability to target reductions in NASA's long term liability associated with its most challenging remediation sites. The task order was constructed in two phases. Phase 1 consisted of gathering data, conducting interviews with each Remediation Project Manager (RPM) followed by an analysis of the data within a final report for submittal to NASA HQ. This report focused on the past, current and future technologies employed or considered at the NASA Centers and Component Facilities (CF). In continuation of Phase 1, the follow-on Phase 2 of this task order assessed and evaluated NASA's remediation efforts. In addition, Phase 2 served to reduce NASA's environmental liability through the use of new, innovative or emerging technologies and by identifying opportunities for reducing costs and/or time to cleanup. The development of a collaborative partnerships amongst the RPMs, NASA HQ EMD and ITB was of significant importance throughout this project.

> NASA Environmentally-Driven Risk Reduction
> Contract (NNH009CF09B) Task Order NNH10AA15D April 21, 2010
>
> **1.0 EXECUTIVE SUMMARY**
>
> ITB, Inc. is pleased to submit our task order plan and cost proposal to provide support for Phase 1 of NASA's Remediation Technology Collaboration Development Task. The purpose of this task is to establish the capability to target reductions in the long-term liability associated with NASA's most challenging remediation sites. This task order consists of two phases. Phase 1 will be concerned with the current technology baseline documentation and awarded first. Phase 2 will be the identification of technology and potential partnerships and awarded later. For this proposal, ITB has proposed only the efforts associated with Phase 1. Accomplishment of Phase 1 will occur by forming a baseline of deployed site remediation processes/conditions utilizing already-available resources. Our emphasis on teamwork with all organizations and our dedication to quality processes are cornerstones of our performance. ITB has a strong record of technical and management performance on multiple task order contracts and brings proven and current NASA expertise in support of this effort.

Phase 1 of the RTCD task was completed in December 31, 2010 (Task Order No. NNH10AA15D) and concluded with the delivery of a final report. This report documented major liability drivers for NASA, in terms of cost and technical difficulty. Additionally, working relationships with the RPMs at NASA Centers and CFs and Remediation Liaisons at HQ/EMD were developed during the execution of Phase 1.

Recommendations

Several factors became known during this task: 1) Every NASA Center/CF is under some form of remediation, 2) contamination at many of the sites is extensive and widespread, 3) clean-up would require a considerable amount of resources, and 4) various technologies either have been used, are in use or have been considered already. In addition, based on the COC's involved, their concentrations and each site's unique geology and hydrogeology, successful use of remediation technologies resulting in closure is generally considered to be site specific. With that in mind, ITB concluded and recommended to EMD that the following Centers/CFs offer the greatest opportunities for investment to seek enhanced and/or alternative remediation technologies – MAF, SSFL and WSTF.

Additional information supporting these decisions are found in Section 4.0 Conclusions/Recommendations of Phase 1 Final Report (Appendix 1 - NASA.NNH10AA09D15D.RPT.FinalPhIRTCD.WO.12.28.10.pdf).

Based on the above factors, ITB also recommended that NASA implement the Phase 2 portion of the RTCD task order. This phase was expected to allow the ITB team to identify and target those sites either under remediation or expected to be under remediation with a view toward reducing NASA's long term cost and/or time liabilities, (for example, opportunities to eliminate long-term P&T and the integration of low cost/energy treatment options). Strategies for identifying these opportunities were derived from an in-depth analysis of the baseline data collected during Phase 1.

Phase 1 Technical Approach

ITB executed this phase as five accumulative steps: 1) preliminary information gathering; 2) interview with NASA EMD Liaisons; 3) survey NASA Centers; 4) analysis of findings, and 5) reporting.

Step 1 was conducted and completed between May 1, 2010 and July 1, 2010. This step focused on collecting all available information on NASA's environmental remediation efforts from readily available sources such as the internet, NASA websites, US EPA sources, and State-specific websites, such as the California Department of Toxic Substances Control.

Step 2 was a meeting with EMD liaisons at NASA Headquarters, Washington D.C. This occurred on July 7, 2010. ITB personnel met with the NASA ECR Program Manager as well as four EMD Liaisons. The meeting was very productive and resulted in EMD introducing ITB to the Center/CF RPM's. Furthermore, EMD guided ITB in developing a series of checklist-type spreadsheets in preparation for contacting and surveying the Center/CF RPM's. These spreadsheets were populated with specific information each site's COC's, the affected media type (soil and/or groundwater), and the remediation efforts (past, current and future). The spreadsheets were then sent to each of the Agency's RPMs as a point of reference prior the surveys.

Step 3 focused on contact between ITB and Center RPM's. This primarily took place between August 15th and November 1st (2010), and continued throughout Phases 1 and 2. Within a relatively short period of time, ITB was able to gain a full understanding of each remediation site[7] at NASA's 15 Centers/CFs. Realities and challenges included site-specific contaminants involved, the source of contamination, subsurface conditions, pilot studies and remediation efforts to date, sensitive receptors[8] that could be threatened by contaminate exposure, the regulatory environment, and most importantly the technology employed to remediate and clean up the contamination(s).

Step 4 was an analysis of the information gathered concurrently with Step 3. As ITB engineers acquired more data and began to fully understand NASA's environmental efforts, they also analyzed the data with an eye toward identifying the liability drivers at each site. Likely examples of these liability drivers included:

- The unfunded liability cost (i.e. UEL, as explained in Section 3)
- Intended site use upon closure (What is the Center going to do with the site once remediation activities are complete?)
- Duration of cleanup (How much time is needed to complete remediation?)
- Opportunities for alternative remediation and energy technologies for reducing energy costs

Step 5 – Delivery of the RTCD Final Report before December 31, 2010.

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[7] Hundreds of clean-up sites, past and present

[8] EPA - What are Sensitive Receptors?

Summary

The ITB Team analyzed the collected data from Steps 1 through 3 so as to develop and identify the drivers primarily as they pertained to cost and technical difficulty. By determining the unfunded costs in reaching site closure and estimating how long each specific site will be in remediation, an assessment of opportunities for technology investment was presented to NASA to assist in reducing its overall liabilities (costs, time, energy consumption, etc.). A brief synopsis of each Center's impacts to soil and groundwater, and the impact to sensitive receptors was provided in support of this assessment (refer to Appendix 1 – RTCD Phase 1 Final Report Section 2).

As part of this assessment, several factors were considered:

- The nature and mechanics of the substrate at each site and its influences on soil and groundwater contamination
- The contaminants of concern at each site
- The mechanics and nature of groundwater plumes, its lateral and vertical extent and its impact on the Centers/CFs, surrounding communities, and natural environment
- Impacts to or the threat of impacts to sensitive receptors in the area
- The state of cleanup and remediation at the current time, i.e. progress of cleanup efforts at those sites under remediation, and their prognosis of success
- Total [estimated] life-cycle costs associated with a particular site and its proposed remediation technology

Additional Comments and Recommendations

ITB recommended that NASA implement the Phase 2 portion of the Remediation Technology Collaboration Development task as a means to further identify opportunities to reduce NASA's long-term cost and/or time liabilities. In addition to identifying new and emerging technologies, adopting more environmentally preferable, sustainable technologies were considered for reduction of a site's lifecycle clean-up costs.

See Appendix 1 - NASA.NNH10AA09D15D.RPT.FinalPhIRTCD.WO.12.28.10.pdf.

2011 – Phase 2; 60 Day Summary:

This two-month period summarized the first 60 days of National Aeronautics and Space Administration's (NASA's) Technology Evaluation for Environmental Risk Mitigation (TEERM) Remediation Technology Collaboration Development (RTCD) Project – Phase 2. This brief "preview" was intended to solicit early inputs from NASA EMD that could modify/redirect the Phase 2 efforts, and served as a foundation on which to build subsequent deliverables. Moreover, the Summary period sought to confirm that ITB, Inc. (ITB) is following the intent of the Statement of Work. A Summary Report was formally delivered to EMD for review on April 5, 2011.

As part of this task order, ITB representatives attended NASA's Remediation Project Manager (RPM) Workshop in Huntsville, Alabama in March 2011. During the Workshop, RPMs from Stennis Space Center (SSC) presented a need for assistance from ITB in determining the best course of action regarding their upcoming 5-year remediation status review. Additionally, SSC RPMs expressed their concerns with aging and obsolete pump and treat (P&T) groundwater treatment systems. As a result, ITB added SSC to the initial focus list of Centers and CFs.

Table 2 presents a brief summary of the alternative remedial technologies that were identified by ITB for reducing remediation cost and schedule at selected NASA Centers/CFs. Of the eleven technologies identified, five were in-situ groundwater and/or soil treatment reagents, three alternative/sustainable energy sources, one is a nano-scale contaminant recovery material, one is a P&T system optimizing process, and one is an electrical solid waste treatment process.

TECHNOLOGY	SSFL	WSTF	MAF	SSC
ZeroBase Energy, LLC (portable solar arrays to power remediation systems)	X	X	X	X
Merrifield Engineering, Inc. (portable solar arrays to power remediation systems)	X	X	X	X
GlassPoint Solar, Inc. (concentrated solar to produce steam for enhanced contaminant recovery)			X	X
VeruTEK Technologies, Inc. - S-ISCO® (activated persulfate for in-situ oxidation of NDMA in GW)	X	X		
VeruTEK Technologies, Inc.- AMO (enhanced photodegradation to compliment ex-situ UV oxidation of NDMA in GW)	X	X		
ABSMaterials, Inc. - Osorb (VOC recovery with nano-scale glass media & hydrogen instead of GAC units)	X	X	X	X
Planteco Environmental Consultants, LLC - SAMNAS® (bioremediation/phytoremediation process to address perchlorate in soil and groundwater)				X
Planteco Environmental Consultants, LLC - MuniRem (sulfur-based compound for in-situ GW and soil treatment of NDMA)	X	X		
inVentures Technologies, Inc. - gPRO®HP (pump and treat optimization)	X	X		X
Battelle, Ferratec, LLC, Florida Institute of Technology - Ferrate (oxidizer, coagulator for in-situ/ex-situ GW treatment)	X	X		X
Georgia Tech Research Institute (in-situ/ex-situ plasma vitrification of soil to replace off-site disposal)	X			
Notes: X = Applicable to this NASA Center/CF, ISCO = In-Situ Chemical Oxidation NDMA = N-nitrosodimethylamine, GW = Groundwater, AMO = Amorphous Manganese Oxide, VOC = Volatile Organic Compound, GAC = Granulated Activated Carbon				

Figure 3 Initial alternative remedial technologies identified by ITB

Discussion of External Partners

Nine potential partners external to NASA were identified for outreach by ITB during Phase 2. These groups and organizations shared certain site characteristics and/or overall remedial goals with selected NASA Centers/CFs.

- U.S. Army Garrison, Kaiserslautern, Germany
- Battelle Memorial Institute Environmental Technology Verification (ETV) Program
- The Aerojet General Corporation Superfund Site, Sacramento, CA
- U.S. Department of Transportation John A. Volpe National Transportation System Center
- Savannah River National Laboratory (SRNL)
- U.S. Air Force Center for Engineering and the Environment (AFCEE)
- U.S. Naval Facilities Engineering Service Center (NAVFAC-ESC)
- U.S. Army Environmental Command
- Interstate Technology & Regulatory Council (ITRC)

See Appendix 2 - NASA.NNH11AA22D.RPT.RTCDPh2-60DaySummary.WO.JR.04.04.11.pdf).

2011 – PH2 (Period of Performance - January 1, 2011 to December 31, 2011)

The twelve month RTCD Phase 2, completed on December 31 2011 (Task Order No. NNH11AA22D), continued the efforts of Phase 1 by researching existing and emerging technologies that could potentially reduce remediation cost and schedule if implemented at NASA remediation sites. Several opportunities for collaborative technology demonstrations and evaluation projects were developed and proposed. Potential partners in government and industry were also identified and pursued concurrently. The final RTCD Phase 2 report was delivered to NASA EMD on December 30, 2011. However, a mid-term draft report was created to elicit feedback and suggested improvements from EMD, all of which was incorporated into the final report.

ITB's analysis during this period continued to focus on four NASA locations that offered the best near-term project implementation opportunities: Santa Susana Field Laboratory (SSFL), White Sands Test Facility (WSTF), Stennis Space Center (SSC), and Michoud Assembly Facility (MAF).

- SSFL – Technologies:
  - Onsite (ex-situ) Chemical Treatment of Contaminated Soil
  - In-situ Chemical Oxidation (ISCO) of TCE in Groundwater
  - Onsite (ex-situ) Plasma Vitrification of Contaminated Soil
- WSTF – Technologies:
  - Ultraviolet (UV) Photochemical Degradation Enhancement
  - High-Efficiency UV Lamps and UV Chambers
  - ISCO of Contaminated Soils using Horizontal Direction Drilling (HDD) for Injection
- SSC – Technologies:
  - ISCO of TCE in Groundwater including a "mini-Feasibility Study" with EN Rx
  - Ex-situ Treatment of TCE Using Nano-scale glass, Palladium, and Hydrogen
  - In-situ Real-Time Monitoring of TCE in Groundwater
- MAF – Technologies:
  - Sustainable Energy Sources
  - Vapor Intrusion Detection and Mitigation

At the request of EMD, ITB included NeoTech Aqua Solutions, Inc. in the list of potential technologies for use at WSTF. NeoTech (formerly UV Sciences) is the manufacturer of a more efficient ultraviolet lamp for use in UV treatment of NDMA in groundwater.

Additionally, new Partners were added:

- Carlos Pachon, Office of Superfund and Technology Innovation
- Mike Gill of EPA's Region 9 Office of Research and Development
- Ms. Nancy Ruiz, Environmental Engineer at Naval Facilities Engineering Command (NAVFAC)
- The Federal Remediation Technologies Roundtable (FRTR)

Three opportunities for technology demonstration were generated from the PH2 effort, all at SSC:

- EN Rx ISCO Pilot Test Proposal
- ABSMaterials VOCEater Pilot Test Proposal
- Developing Technology - Real-time Quantitative Measurements of TCE in Groundwater

In addition to the further development of the technologies and partnerships listed above, ITB continued the NASA's Annual Status Report on Remediation Technology (developed during RTCD Phase 1). A data call was requested from each RPM to obtain updated information appropriate to their respective sections of the Phase 1 report (e.g. current status of open sites and technologies applied, etc). The data was compiled and delivered to EMD as part of the Phase 2 Final Report.

Separately, EMD requested that ITB pursue information regarding a bioremediation research project being conducted at Ames Research Center (ARC). An introductory teleconference was held on August 19, 2011. Following the teleconference, Dr. Ken Cullings (lead scientist), provided a description of the bioremediation technology research at ARC in a letter to ITB, which is included in section 4.0 of the RTCD PH2 report ***(see Appendix 3 - NASA.NNH11AA22D.RPT.FinalRTCDPh2.JR.WO.12.30.11.pdf)***

RTCD 2012 (January 1, 2012 to December 31, 2012):

As part of the third year of NASA's RTCD task order (NNH12AA38D), ITB Inc. continued from the previous years' activities, and suggested newly-proposed projects as well. The on-going purpose of the RTCD task continued to establish the capability to target reductions in the long-term liability associated with NASA's most challenging remediation sites. A final report focused on events that occurred during this task period while leveraging upon the work completed during RTCD Phase 1 (2010) and RTCD Phase 2 (2011). As a result of the RTCD Phase 1 efforts, ITB identified four NASA locations that offer the best near-term opportunities to reduce environmental remediation liabilities: Santa Susana Field Laboratory (SSFL), White Sands Test Facility (WSTF), Stennis Space Center (SSC), and Michoud Assembly Facility (MAF). Although RTCD Phase 2 and RTCD 2012 efforts continued to focus mainly on these four locations, the applicability of technologies and partners to other NASA Centers and CFs was always a consideration.

The ultimate and continued goal of the RTCD task was to propagate partnerships and implement successful technologies across the Agency. For example:

ISCO Pilot Test at SSC

The results of a technology field demonstration, proposed as part of RTCD Phase 2 but conducted during RTCD 2012; a successful in-situ chemical oxidation (ISCO) pilot test was coordinated by ITB, and executed at SSC during the spring and through mid-summer of July 2012. Based on this success, SSC expanded the ISCO contractor's (EN Rx, Inc.) activities to full-scale implementation at cleanup Area G. During August 2012, additional assessment activities were initiated by EN Rx, Inc. as part of the full-scale implementation. Initial full-scale treatment efforts also began during this time, and concurrent to the assessment activities. The assessment revealed that the amount of source contaminant mass located in Area G was greater than anticipated. Additional assessment was required to fully understand the magnitude of the remaining contaminant mass, and the associated cost of complete remediation of Area G by ISCO. At the time, SSC was not prepared to fund a larger remediation effort than initially expected, and additional full-scale ISCO treatment was postponed until the remaining contaminant mass could be fully delineated. ITB recommended, and SSC agreed, that a "site-wide" *reassessment* of their cleanup areas was needed prior to committing to any full-scale remediation project. As a result, SSC tasked EN Rx, Inc. with conducting a full and complete delineation of Area G prior to additional ISCO treatment.

Overview of the innovative characteristics of EN Rx's product and process that contributed to success at SSC, and anticipated for other NASA Centers and CFs as well.

- The slow injection rate (4,000 pounds of reagent over 4 mos. at SSC) and slow reacting oxidizer could potentially address the effects of matrix diffusion and groundwater concentration rebound.
- The low-energy system is powered by public utility water pressure and small solar panels using consumer off the shelf (COTS) components.
- NASA personnel were trained to operate and maintain the system to reduce contractor site visits.

- Peroxide was provided by the client (the only long term consumable required from EN Rx will be proprietary activator).
- The injection system included capabilities for remote monitoring and control remotely using a web-based software interface.

SSC considered this Area G pilot test a success and expanded EN Rx's activities to the north of the pilot location.

New technologies Identified:

Groundswell Technologies, Inc. - Earth Monitoring Software

ITB identified Groundswell Technologies, Inc. (GT) of Santa Barbara, California as a leading-edge innovator in the area of data visualization in response to a request for assistance from SSFL in February 2012. GT conducted a series of presentations of their cloud-based software platform to demonstrate their capabilities. A demonstration integrating actual SSFL data into the software system was conducted on August 7, 2012. Key NASA personnel agreed that the software could provide value and aid the remediation efforts at SSFL, mostly in the areas of data organization and visualization, stakeholder participation, and data gap identification.

BioStryke™ (previously Plant Products®)

ITB identified and collaborated with a Canada-based fertilizer company that offered small amounts of their BioStryke™ bioremediation amendments products at no cost in order to conduct onsite treatability studies/pilot tests. For the purposes of facilitating a quick and easy pilot test, amendments were shipped to a test site packaged in "Passive Release Socks" (PRSs). These PRSs are lowered into any available 2-inch diameter groundwater monitoring well containing organic contaminants. The results of the pilot test can be used to determine if the site-specific conditions are amenable to full-scale "bio-stimulation" implementation. ITB envisioned the execution of a BioStryke™ pilot test at SSC. A comparison to the ISCO pilot test completed in July 2012 was interesting because the BioStryke™ technology is conversely related to ISCO i.e. it is a biological degradation requiring anaerobic conditions as opposed to chemical degradation requiring aerobic conditions. ITB coordinated an on-site meeting with SSC RPMs and Kent Armstrong of BioStryke™. The meeting took place at SSC on December 20, 2012.

Recap of identified technologies and new partners

- SSFL
  - Radio Frequency (RF) Thermal Remediation
  - In Situ Chemical Oxidation (ISCO) of Trichloroethylene (TCE) in Groundwater
  - Onsite (Ex Situ) Chemical Treatment of Contaminated Soil
  - Technical Impracticability (TI) Waiver
- WSTF
  - High-Efficiency Ultraviolet (UV) Lamps and UV Reaction Chambers
  - ISCO of Contaminated Soils using Horizontal Direction Drilling (HDD) for Injection
- SSC
  - Bioremediation Amendments (Bio-stimulation)
  - In Situ Real Time Monitoring of TCE in Groundwater
  - Ex Situ Treatment of TCE Using Nano-scale Glass, Palladium, and Hydrogen
- MAF
  - Electro-kinetic Placement of In Situ Amendments and Reagents
  - Sustainable/Renewable Energy Sources for In Situ Thermal Remediation (ISTR)

- Vapor Intrusion Detection and Mitigation
- Electrical Resistance Heating for ISTR
- Onsite GAC regeneration

- Agency-wide
  - Visualization software: ARCADIS and Groundswell
  - Real Time Sensors for Detection of Solvents in Groundwater (GTRI)
  - Geosyntec Consultants – Titusville, FL
  - Geosyntec Consultants - Technical Impracticability (TI) Waiver by EPA.

In addition, ITB completed an update to the Summary of Remediation Technologies at NASA (to the 2010 Baseline). This added task drew from the previous year's summary report and contained the latest information on the current conditions and in-use or proposed technologies for each remediation site at each facility. The data obtained was compiled on a spreadsheet and submitted along with this task's final report.

2.2.1 Current Technology Baseline Documentation

2.2.1.1 Task 1 - Annual Review of Remediation Technologies

1. Using already-available resources (such as the ECR Program Manager, RPMs and Liaisons, NETS Projects, the UEL data, remediation workshop presentations, NASA's NSC Knowledge Now website, etc.) document the current conditions and in-use or proposed technologies for each remediation site at each facility

2.2.1.2 Task 1 Deliverables

1. Compile data from Task 1 into the *Summary of Remediation Technologies at NASA* (Baseline Report - Microsoft Excel) and submit to EMD by December 31, 2012.

Figure 4 Extracted from the April 2010 RTCD SOW

Summary: RTCD 2012 efforts leveraged upon the work completed during Phases 1 and 2. Previously identified technologies were further investigated to determine value to NASA. Relations with previously-contacted potential project partners were strengthened. In addition to building on past efforts, the RTCD task evolved and reacted in order to efficiently address the most current and urgent needs of NASA's RPMs in 2012. New technologies and partners were identified to address changing priorities and conditions. Pursuit of some technologies and partners was suspended after new information could not justify continued efforts.

In accordance with the schedule outlined in the January 23, 2012 Task Order Plan, ITB submitted a final report to NASA on December 31, 2012. The purpose of the report was to present a general summary of the cleanup challenges faced by NASA at four select locations and to document the developments and achievements of RTCD 2012.

Furthermore, ITB had observed a recurring theme at many of NASA's cleanup sites; more assessment/re-assessment is required before realistic expectations of remediation effectiveness can be determined. In order to respond to this immediate need, ITB turned its focus towards innovative assessment technologies in 2013 in addition to the continued pursuit of alternative remediation technologies and process optimization.

See Appendix 4 - NASA.NNH12AA38D.RPT.2012FinalRTCD.JR.WO.12.21.12.v4.pdf

2013 – MOD 1 (January 1 – July 31)

As a result of the U.S. Government Budget Sequestration[9], a seven-month extension to the 2012 RTCD Task Order was granted. This MOD 1 period covered ITB's performance under Task Order NNH12AA38D, NASA Remediation Technology Collaboration Development (RTCD), from January 1, 2013 till July 31, 2013. The work performed under this task order continued to increase ITB's capability to specifically target reductions in the long-term liabilities associated with NASA's most challenging remediation sites. Additionally, project development and planning for demonstration and validation of alternative remediation technologies/products, as well as associated outreach, was included during this period.

As a result of the MOD 1 extension, and RTCD Task Order becoming more "program-like", ITB initiated the appropriate management style which was more effective for on-going activities (e.g. not bound by or limited to funding periods). In addition, this process improvement included a streamlined Activities/Status Update Report in lieu of the voluminous end-of-year final reports.

2013 – MODs 1 & 2 (January 1, 2013 – January 31, 2014)

This thirteen-month period covered ITB's performance under Task Order NNH12AA38D, NASA Remediation Technology Collaboration Development (RTCD), MODs 1&2 between January 1, 2013 and January 31, 2014. The work performed under this task order continued to increase ITB's capabilities to specifically target reductions in the long-term liabilities associated with any remediation site within NASA. In addition:

- ITB developed and proposed the concept for an online data entry tool to support the Annual Summary of Remediation Technologies (See Section 6 - NETS ECR Technologies Module)

Activities:

- RTCD module within NASA Environmental Tracking System (NETS)
    - Streamlined the process for updating the database - Annual Summary of Remediation Technologies at NASA.
    - Provided an opportunity to consolidate and standardize the terms and nomenclature used by the RPMs when identifying clean-up technologies and contaminants for concern.
    - Initial discussions with EMD and the NETS Program Administrator were successful in determining the best course of action for creating a RTCD module within NETS. Additional comments from the EMD ECR Manager helped clarify the NETS database structure and, as a result, narrative-type information was easily converted into importable data.
    - As suggested, the NETS RTCD Module would include:
        - Drop-down menus for selecting site-specific clean-up technologies
        - Checkbox menus for selecting site-specific contaminants of concern (COCs)
        - Included Center/Component Facility baseline data (2010) and annual updates as well
        - "Carry forward from previous year" functionality
- Electrical Resistivity Imaging (ERI) - Non-invasive Biowall Monitoring, an emerging lower-cost alternative for measuring/monitoring the effectiveness of permeable reactive barriers (biowalls).
- Harris Radio Frequency (RF) Remediation (RF Heating)
    - Harris Corporation is developing a RF in situ thermal remediation technology that, in ITB's estimation, could be useful at SSFL. During meetings with Harris Corp., they offered to conduct

[9] United States budget sequestration in 2013 - Wikipedia

the initial analysis of rock cores in their lab in Melbourne, FL at no cost to NASA in order to get a pilot project started. ITB promoted this partnership and technology as an opportunity for NASA.

- Bioremediation Treatability Study (Area D at SSC)
  - Project Description: Conducted both laboratory and field treatability studies on groundwater from Water Bearing Zone (WBZ) 3 at Area D of SSC (monitoring well 06-12 MW) using bioremediation techniques. No NASA ECR funding request was necessary since the project vendors offered their services and products as in-kind
  - Project objective was to conduct a laboratory treatability study of a proprietary bio-stimulation with bio-augmentation technology, and a field study at SSC of an alternative proprietary product for removing TCE in groundwater
  - Determine whether innovative sensors offering a quick, semi-quantitative characterization could be useful and viable at SSC

- EN Rx ISCO at SSC (primarily at Area G)
  - This project continued from the previous year (2012). In addition:
    - EN Rx gave an on-site presentation at SSC
    - Assessments were implemented at Area G and Area F, and are considered for Area C
    - *EN Rx offered a performance based remediation strategy at Area G*
    - Another opportunity suggested a HDD project at Area B
    - The RPMs at ARC and WSTF expressed interest in applying the EN Rx technology at their locations

- BioStryke® Remediation Products, LLC
  - Summary of objectives and protocols necessary to implement an in-situ groundwater bioremediation Proof-of-Concept evaluation at ‘Area D’ at SSC; specifically, within groundwater Horizon 3, monitoring wells MW-06-12

- Microbial Analysis and Bioreactors - Ken Cullings (ARC)
  - Proposed - Agency-wide Meta-analysis of Microbial Populations in Mixed-contaminant Groundwater Plumes
  - Discussions with Keith Fields on the JPL Bioreactor
  - Monitored Natural Attenuation: A Molecular Approach (fingerprinting)
    - Telecon with EMD and the RPMs (July 15, 2013)

- Space-based Hyperspectral Imaging for Environmental Assessments
  - Driver - some environmental clean-up strategies at NASA Centers and CFs are based on incomplete and/or outdated site assessments and characterizations
  - Proof of Concept completed – space-based HyperSpectral Imaging (HSI) technologies can provide data for environmental and geological users.
  - Proposed project leverages MSFC’s ground-based HSI environmental assessment technology along with the existing (aboard the ISS) Hyperspectral Imager for the Coastal Ocean and Remote Atmospheric and Ionospheric Detection System.
    - Comments: Works by looking at stressors on plants. Technology is advancing quickly with ESA and others as well. MSFC is also developing this technology and is considering flight-testing (flight time is very expensive).
    - Next Steps – lab testing of site-specific vegetative species.

- Horizontal Directional Drilling (HDD) and Matrix Diffusion at WSTF
    - HDD technology is advancing rapidly and the RPM at WSTF has expressed interest (depths of 500 to 600 ft bgs and lengths of 2000 to 5000 ft in the complex geology).
- WSTF Environmental Information Management System (EIMS)
    - ITB requested information regarding the EIMS from the A&E at WSTF, who recently conducted a WebEx demonstration. Potentially, the system could save money by eliminating labor costs associated with well gauging and maybe even sampling (with the correct sensors). Real-time monitoring of the extraction systems' capture zones could be accomplished remotely via a secure internet connection.

Other Reports/Papers:

- National Academies of Science (NAS) presentation
    - Assisted the NASA HQ/EMD ECR Manager in developing a presentation to the *NAS; NASA Perspectives on Fractured Rock*
- MAF ISTD Pilot Study Report, per request from the ECR Manager
    - ITB reviewed the NASA Michoud Assembly Facility AOC D (RWA-2) In-Situ Thermal Desorption Pilot Study MO-2 Evaluation Report prepared by Great Southern Engineering, Inc. (GSE) of Trinity, Alabama in September 2012 for the Environmental Engineering and Occupational Health Office at NASA/Marshall Space Flight Center in Huntsville, Alabama. The report presented a brief overview of the project and the findings, comments, and recommendations.
- Bioreactor White Paper (ARC – Ken Cullings)
    - The use of bioreactors for groundwater remediation is not a new idea. Literature can be referenced on the subject dating back to the 1980s. What appears to be missing from the literature is the use of site-specific microorganisms obtained from an actual mixed-contaminant groundwater plume in a bioreactor to treat that specific plume. A significant and distinguishing feature of this project is that it identifies microbes and their associated enzymes that have adapted to site-specific conditions as opposed to a "one-size fits all" bio-augmentation solution that is currently available commercially. Each analysis requires only five grams of sediment collected from an existing groundwater monitoring well, and shipped overnight to Dr. Cullings at ARC. There is no need to drill additional sampling wells. There are five additional NASA Centers/CFs that use P&T technology.
- NASA-Wide Fact Sheet on TCE (with Focus Group)
    - Per request by NASA HQ EMD, ITB assisted the FOCUS GROUP with the preparation of a fact sheet that elaborated on NASA's efforts regarding TCE—pursuing cleanup, technologies, etc.
- SSC ISCO one-page "Tech Sheet" for NASA EMD
    - *Project Profile: In Situ Chemical Oxidation (ISCO)*
- White Paper: Conceptual Benefits and Approach for Implementing High Resolution Site Characterization at SSC - Geosyntec (presentation on VI)

Summary

During a December staff meeting, ITB engineers gave an overview of RTCD task from its inception/activation in May 2010, highlighted “value added”, and identified opportunities for future work and forward planning. For example, ITB researched seven (7) site remediation/characterization technologies in depth and more than 30 others to a lesser degree. This resulted in the initiation of three (3) remediation technology pilot studies/demonstrations in which nearly fifty percent of the costs were provided in-kind by participants outside of the Agency. The development of a new reporting module within NETS to incorporate the annual Summary of Remediation Technologies was proposed as well.

The RTCD program continued to add value to NASA by fulfilling requirements to independently review Center/CF technologies, identify advances and provide unbiased recommendations to reduce NASA’s long-term cleanup liabilities. NASA HQ EMD concurred that the RTCD task added value to the ECR Program (PMR, November 5, 2013). ***See Appendix 5 - NASA.NNH12AA38D.RPT.DRAFT RTCD Final Report 2013.WO.01.31.14.v5.pdf***

2014 – MODs 3 & 4 (February 1, 2014 – February 28, 2015)

This thirteen-month period covered ITB’s performance under Task Order NNH12AA38D, NASA Remediation Technology Collaboration Development (RTCD), MODs 3&4 between February 1, 2014 and February 28, 2015.

Scope:

As per the MOD 3 SOW: The Contractor shall develop and propose collaborative projects to perform together with outside partners to validate technologies for actual application at NASA clean-up sites. Technical opportunities the Contractor shall explore for development into active projects include, but are not limited to:

- High Resolution Site Characterization (HRSC) including real-time quantitative measurement of TCE in groundwater and web-based visualization of data
- Assessment and treatment (if required) of soil and groundwater using Horizontal Direction Drilling (HDD)
- Bioremediation of groundwater using novel bio-stimulation and bio-augmentation products and techniques
- Onsite (ex-situ) chemical treatment of soil
- Innovative site characterization technologies
- Real-time sensors for vapor intrusion detection
- Green & Sustainable remediation products, techniques and guidance

Summary

Since the inception of the RTCD task, ITB has focused primarily on determining the most effective (available) and/or emerging clean-up technologies with an eye towards implementation at NASA (second only to establishing an effective “awareness level”). Beginning in early 2014, ITB strived for increased communication and collaboration with EMD, the RPMs and their respective Advocates.

Suggested and Accepted

- Define and formalize the frequency of discussions – Monthly with the EMD ECR Manager
  As per coordination the ECR Manager, the frequency of discussions with ITB was defined and formalized to recur on a monthly basis. In addition, interest in re-establishing the Green & Sustainable Remediation (GSR) Forum as a means to present information to the RPMs, with assistance from ITB, was expressed as well.
- Partner with the RRAC and attend/participate in their RegComm meetings
  Partnering with the RRAC was applicable to the RTCD program since the “RegComm” meetings were an established venue for the RPMs, thereby reducing duplication of effort and attendance.

In addition, ITB continued to:

- Pursue the technologies identified during previous RTCD periods of performance
- Identify new technologies and partners that could help reduce NASA's liabilities regarding environmental cleanup.
- Continue to develop the new reporting module within NETS to incorporate the annual Summary of Remediation Technologies.
- Add value by fulfilling NASA's requirement to:
  - Independently review the remediation and assessment/characterization technologies at each Center and Component Facility to identify areas where advances (from both within NASA and outside partnerships/entities) could be employed to quickly and more efficiently reach closure at NASA's clean-up sites.
  - Provide unbiased recommendations of technically and financially feasible technologies and demonstration partners to reduce NASA's long-term cleanup liabilities.

Success – ITB established the capability to provide significant reductions in demonstration costs to NASA.

Path Forward

For the next effort, CY 2015, ITB proposed the advancement of GSR projects and programs within NASA as a top priority. Items addressed included:

- The continuation of GSR webinars for the RPMs
  - The pursuit of a mechanism/platform to facilitate the open and free exchange of ideas and concerns between RPMs and HQ regarding GSR.
- Provided an independent assessment the remediation program at Langley Research Center (LaRC). This work supported a periodic program review required by NPR 8590.1A and its associated guidance, consisting of the following:
  - Summary of the current remediation status.
  - Effectiveness and appropriateness of current and planned actions in meeting remediation goals.
  - Practicability of current remediation strategy.
  - Determine whether the Center had fully evaluated all innovative technologies that may be applicable, including characterization techniques.
  - Complete a qualitative "Green/Sustainable Remediation" review of current remediation systems in place as relevant and appropriate.
  - Identification of "emerging" contaminants that may impact liability and recommendations for mitigation.

See Appendix 6 - NASA.NNH12AA38D.RPT.RTCD Final Report 2015 wAppen.WO.02.27.15.pdf

RTCD 2015: March 1, 2015 to February 29, 2016

This twelve-month period covered ITB's performance under Task Order NNH15CN32D, NASA Remediation Technology Collaboration Development (RTCD) during March 1, 2015 through February 29, 2016. Activities included:

- Performance-Based Remediation – on-going development (a NASA first)
- Innovative site characterization technologies
  - Hyperspectral Imaging *Systems*
    - Proposed - Agency-wide Plant Species Database to Support Hyperspectral Imaging

    - Environmental Sequence Stratigraphy (AECOM)
- Real-time sensors for vapor intrusion detection
- NETS ECR Technologies Module (evolution of the Annual Summary of Remediation Technologies)
- Risk-Based Corrective Action (RBCA) and/or Risk-Based Closure (RBC)
- Climate Change Resilience and/or Adaptation
- Continue to focus on assessments/characterization while re-addressing Long-Term Monitoring (LTM)
- Comprehensive Overview – RTCD Accomplishments To Date (since May 2010)

Emerging Contaminants

Perfluorinated compounds (PFCs) are found in aqueous film forming foam (AFFF), which may have been used at NASA facilities to extinguish petroleum fires since 1970. The EPA classifies PFCs as "emerging contaminants" based on three characteristics: they have possible pathways to enter the environment; they present a potential unacceptable human health or environmental risk; and they have evolving regulatory standards. For example:

- EPA emerging contaminants - PFOA and PFOS

Identifying cost effective sampling alternatives at WSTF

Currently sampling costs are almost $1.6 million per year

- There are currently 89 conventional wells and 33 Westbay wells, which consist of 91 conventional monitoring zones and 114 Westbay monitoring zones, for a total of 205 active sampling locations
- Additionally, many of the well systems have been converted to low-flow sampling systems, which reduces purge volumes and the associated time to remove three casing volumes before sampling
- Sampling frequencies range from quarterly to biannually. Approximately half of the sampling events are quarterly or semi-annually, with the rest being mostly annually with a few biennial wells
- Typical low-flow wells take about 2-3 hours, standard conventional wells may take 3-8 hours depending on purge volume, and Westbay zones usually take about 5 hours each
- For costs, there are many variables, but taking in account field sampling, related fieldwork support, related materials, and analytical subcontractors, the current annual cost is approximately $1.2 million
    - The above figure does not include cost-tracking, hydrogeological data collection, treatment system sampling, data management, reporting, document prep, waste management, or sample shipment.
    - Including these additional peripheral activities, the total amount is nearer the $1.6 million per year range.

Comprehensive Overview – RTCD Accomplishments to Date (since 2010)

- Researched 11 site remediation/characterization technologies in depth, and more-than 40 technologies to a lesser degree.
- This exploration led to the proposal and initiation of five remediation technology pilot studies/demonstrations.

See Appendix 8 - NASA.NNH15CN32D.RPT.RTCD Final Report 2015.WO v2.02.29.16.pdf

2016 – March 1, 2016 – February 28, 2017

This twelve-month period covered ITB's *final* performance activities under Task Order NNH15CN32D, NASA Remediation Technology Collaboration Development (RTCD) for the period March 1, 2016 – February 28, 2017.

ITB continued to manage previous efforts for reducing NASA clean-up costs and schedule.

Simultaneously, ITB developed and proposed to NASA EMD collaborative projects to validate the technologies for actual application at various sites throughout the Agency. New and on-going technical opportunities identified for development into active projects included (but were not limited to):

- In-situ Real-Time Monitoring of Trichloroethylene (TCE) in Groundwater
- In-situ Chemical Oxidation (ISCO) of TCE in Groundwater
- ISCO of Contaminated Soils using Horizontal Direction Drilling (HDD) for Injection
- Agency-Wide Analysis of Sites Where Risk-Based Closure Can Be an Effective Alternative
- Determine the Potential Effects of Climate Change on Existing Clean-Up Sites
- Ultraviolet (UV) Photochemical Degradation Enhancement
- Sustainable Energy Sources to Support Remediation Technologies
- Vapor Intrusion Detection and Mitigation

In addition, as per Section 2.2.9 of the 2016 RTCD Statement of Work (SOW), ITB conducted an Agency-wide analysis of Industrial Control Systems (ICS) that support cleanup operations. This sub-task, with its August 1, 2016 deliverable date, was ITB's primary focus for this task order during its first five months.

The driver for the ICS sub-task was a NASA OIG Office of Audits "Active Project" (at that time):

> A-16-001-00 **Audit of Industrial Control System Security within NASA's Critical and Supporting Infrastructure Objective**
>
> The overall objective is to evaluate whether NASA has appropriately identified and protected critical and supporting infrastructure.

Accomplishments, Implementations and Opportunities - Highlights

- Implementation of Performance-Based Remediation (PBR) Contracting Strategy (continued since 2013)
  For specific information regarding PBR at SSC, please see Section 6 within this document.
- Review of Risk-Based Closure Options at Area D – Stennis Space Center
  ITB initiated an RBC project at Area D – currently funded and on-going. See Section 7 within this document.
- TCE Groundwater Plume at Goddard Space Flight Center

  The RPM at the Goddard Space Flight Center (GSFC) reached out to ITB regarding the TCE plume at Greenbelt and requested assistance for an optimization/remediation assessment. To note for this TCE site, GSFC received a No Further Action (NFA) letter from the state with the following stipulations:

  - Maintain Land Use Controls (LUCs)
  - Ensure that the TCE plume doesn't migrate offsite
  - Clean-up requirement status is "Voluntary"

  A pilot study was previously conducted to evaluate technologies to control the TCE plume in the event that evidence shows it migrating off base. The current technology is monitored natural attenuation. As such, several monitoring wells were installed at the fence line and the data suggested that the plume may, indeed, migrate offsite in the near future. Sample results for TCE at one of the fence line wells was at 2.6 µg/L and 58 µg/L about 100 feet up gradient.

  GSFC, with assistance from ITB, evaluated options to reduce concentrations in the source area and contain the plume down gradient. (See Section 6 within this document)

Ongoing Activities

- RTCD module within NETS ECR (continued from 2014)

  Overview of the Environmental Compliance & Restoration (ECR) module within the NASA Environmental Tracking System (NETS):

  - Served as an important and valuable information source (i.e. focal point) for the recent ICS sub-task which saved a considerable amount of time in the process.
  - Provides an opportunity to consolidate and standardize the terms and nomenclature used by the RPMs when identifying clean-up technologies and contaminants for concern.
  - Streamlines the process for updating the Annual Summary of Remediation Technologies at NASA database. What took months to complete previously is now a five to fifteen minute end-of-year task for each of the RPMs.

- Hyperspectral Imaging (continued from 2013)

  Hyperspectral Imagining allows for the classification, identification, and detection of vegetation phenomena that relate to a wide range of applications to include: species identification, insect and disease detection/monitoring, fire risk analysis, stress detection, geo-botanical analysis for oil/gas exploration, invasive species mapping (terrestrial and sub aquatic), crop residue, soil quality/tillage, vegetative health, precision agriculture and seed stock tracking.

- Real-time Sensors for Vapor Intrusion Detection (ongoing since 2012)

  Indoor air quality concerns develop when vapors from contaminated soil and groundwater enter buildings and other facilities. To counter this as a risk mitigation effort, contaminant sensor networks and technologies can be used to detect known and new contaminants of concern. In addition, the EPA is proposing to integrate vapor intrusion (VI) into the hazardous ranking system to determine whether a site qualifies for National Priorities List (NPL) status. This potential development was an area of interest for ITB.

  An example of a real-time sensing technology for VI was identified by ITB; Hartman/Groundswell completed their fifth automated continuous VI monitoring project with the Navy (NAS North Island) since February 2017. As a result, some new discoveries led to optimization of the Navy's remediation strategy, and have decisively confirmed that their mitigation system is working as designed. Regarding cost comparisons, Hartman/Groundswell clearly demonstrates that their approach is not only cost-competitive with manual passive methods currently being accepted by Regulators, but the number of analyses-per-week and the cost-per-analysis results are compelling as well. Test results discovered:

  - Time-based prediction/detection of episodic TCE spikes and intrusion point of entry (cause-and-effect controls over risk)
  - Very slight changes in barometric pressure causing "the ground essentially exhaling TCE into the building"

  Within one minute of detecting a concentration threshold exceedance, the Hartman/Groundswell system sent email alerts to designated parties (Navy RPM and consultants). With traditional methods, sample results often require a week or more for the results (EPA's stated concern is the 24-hr exposure duration). As such, this new VI testing platform allows for risk reduction before it is too late. This successful demonstration has led to the project's extension and expansion at NASA's North Island location.

Path Forward

While this is the final year for the Remediation Technology Collaboration Development task order, a compendium report was proposed, and agreed to by NASA HQ. This report provides a comprehensive overview of the entire RTCD program (2010 – 2017) to include highlights and areas of interest.

See Appendix 9 - NASA.NNH15CN32D.RPT.RTCD Final 2016.WO.02.28.17.pdf

5. Significant Projects, Ideas and Focus Areas

Annual Summary of Remediation Technologies

The Annual Review of Remediation Technologies was a major component of the RTCD Phase I (period of performance May 1, 2010 to December 31, 2010) and consisted of gathering information by performing interviews and surveys with each RPM, analyzing the data and reporting the findings. This "data call" focused on the past, current and planned technologies employed at or expected to be employed at the NASA Centers and CF sites. This baseline also served as reference for EMD's ECR Program.

Table 4, as an example, shows each of the 15 Centers/CFs and the types of remediation technologies that are in use or have been successfully used at one point in time. In addition are technologies that were attempted for use but were rejected for one reason or another, along with some that were considered for use but never actually implemented.

Remediation Technology	Center / Component Facility														
	ARC	DFRC	LF (GRC)	PBS (GRC)	GSFC/GB	KSC	LaRC	JPL	JSC	MAF	MSFC	SSFL	SSC	WFF	WSTF
Administrative and/or Land Use Controls		G			G	G	G			G	G	B	G	G	
Soil Vapor Extraction (In Situ)	G	B				R				B	B			G	
Vacuum Enhanced Groundwater Extraction (VEGE)				G											
Bioventing (In Situ)														G	
Biopiles and Biowalls (Ex-Situ)									B						
Landfarming (biodegradation - Ex-Situ)						G								G	
Thermal Treatment (Ex-Situ)						G									
Thermal Treatment (In Situ)						G				G	G				
Air Sparging (In Situ)	G	B				G						R		G	
Air Stripping (Ex Situ)						G				G					
Biosparging (In Situ)						G									
Monitored Natural Attenuation	G		G	G	G	G	B			B	G	G	G	G	
In Situ Groundwater Bioremediation					B	G				R	G				
Dual-Phase Extraction (bioslurping - In Situ)						G									
Enhanced Aerobic Bioremediation (In Situ)					B	G	B			R	B				
Chemical Oxidation (In Situ)		G				G	B		G	R	R				
UV Oxidation (Ex Situ)						G						R			G
Permeable Reactive Barriers	R				B	G	B			R	B		G		
Nanotechnology						B									
Phytotechnologies						B									
Ground-Water Circulating Wells						G									
Soil Excavation			G	G	G	G				B	G	G	G	G	
Groundwater Pump & Treat	G	R	G	G	B	G	G	G	G	G			G	G	G

Legend
Green: technologies in use or were successfully used
Red: attempted but discontinued or rejected
Blue: considered

Table 3 Initial method to visualize NASA's Remediation Technology utilization

This portion of the RTCD Phase I task was successful in that the summarization of NASA's environmental efforts enabled ITB to gain a better understanding of the clean-up activities throughout the Agency. In addition, the completion of Phase I helped set the stage for the follow-on Phase II Task Order. In other words, now that ITB understood the position and needs of NASA's RPMs, recommendations to improve the effectiveness and efficiency of environmental remediation could begin. In addition, site-specific green and sustainable alternatives could be recommended as well.

The Contractor shall prepare a Summary of Remediation Technologies at NASA. This will be an update to the previous year's summary report and contain the latest information on the current conditions and in-use or proposed technologies for each remediation site at each facility.

It wasn't long before ITB realized the value of this "data" and soon recommended that NASA consider the Annual Summary to be updated on a yearly basis.   While this data was seen as a valuable method for providing a concise, up to date snapshot of NASA's remediation efforts Agency-wide, eventually it could be an effective tool for trend and cost analysis as well. Based on these concepts, it became obvious that aggregating an Excel spreadsheet would not effectively serve as the correct platform. At this point, ITB explored and proposed that NASA include the Annual Summary as a component of its existing NETS database program.

NETS ECR Technologies Module

Concept: "From the initial baseline effort i.e. the *Annual Summary of Remediation Technologies*, evolve this multi-tab Excel spreadsheet into a web interface-supported online data tool."

The intent of the ECR Technologies Module was to increase RPM participation by offering a simplified online tool for capturing and maintaining remediation technology information that could be used for regulatory requirements while streamlining and consolidating the data call processes within NASA.

For this application, ITB designed an intuitive graphical user interface (GUI) that replicated the existing modules in NETS while incorporating the elements needed from the original Annual Summary of Remediation Technologies spreadsheets. Initial discussions with the NETS Manager were successful for guiding ITB's approach for creating this "ECR Technologies" module. In addition, ITB converted thousands of data points from four years' worth of Annual Summaries (hundreds of cleanup sites across 15 Centers/CFs) into a database that was compatible for upload into NETS. Expected benefits of the new module were:

From the 2014 OIG Report, "Centers reported that because NETS is limited in its ability to track and manage projects, they use it only to respond to the annual Headquarters data call. Centers' use of NETS varied to such an extent that the information contained in the system could not generally be relied upon except for when the Centers updated the system in response to the annual Headquarters data call.

- Provide an opportunity for NASA to consolidate and standardize the terms and nomenclature used by the RPMs when identifying clean-up technologies and contaminants of concern
- Offer opportunities for trend/costs analysis
- Serve as a single source point of Agency ECR data for audit type events

ITB demonstrated and provided individualized training of the new ECR Technologies Module within NETS to each RPM. The result was a significant time-savings by the RPMs for providing the annual updates – from days and/or weeks (dependent on a Center's number of cleanup sites and their complexity) to just minutes overall e.g. simple checkboxes and pull-down menus are used instead of typed narratives of the previous Excel spreadsheets. Back and forth emailing of documents and files was eliminated as well.

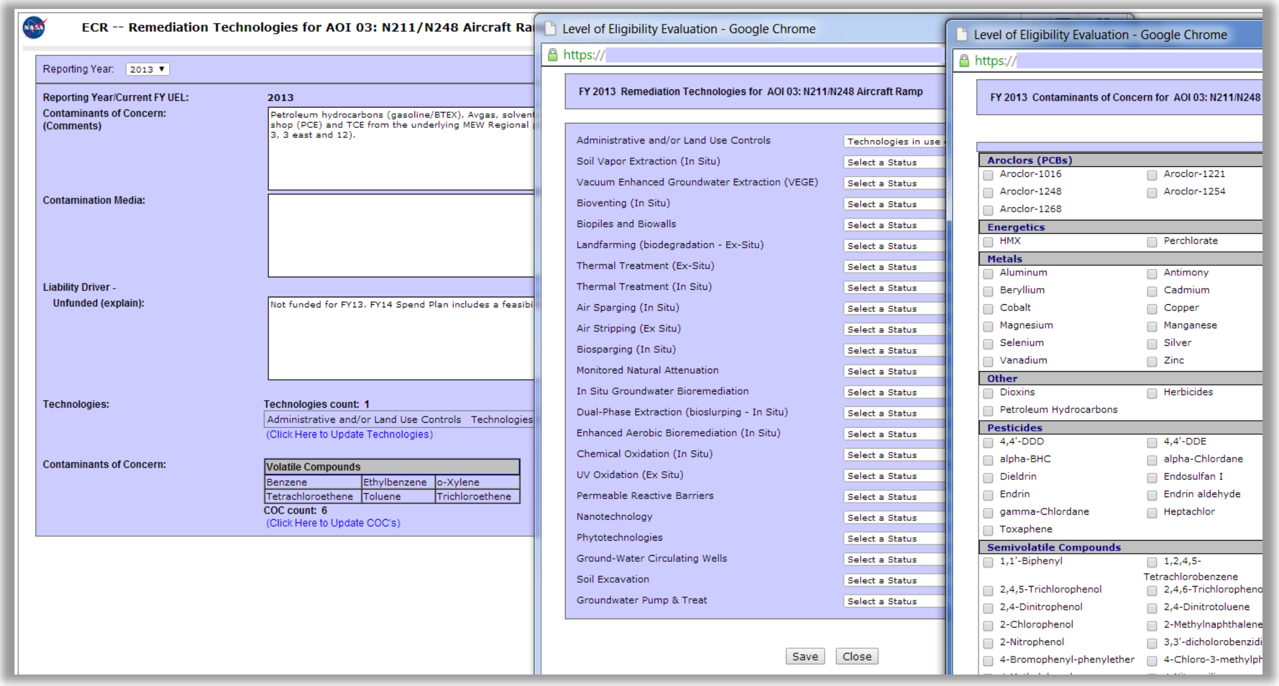

Figure 5 NETS Technologies Module – Early Development

Success – NETS ECR Technologies Module Go-Live Date – September 2015

"As you may recall from the last RPM Meeting (JSC-March 2015) the Annual Summary of Remediation Technologies is now incorporated into NETS (ECR Technologies Module)."

"While the NETS Manager did an excellent job of introducing this module in its beta form, I'd like to conduct a walkthrough with you of its current production/operational format."

"This NETS module paves the way for future annual summaries of remediation technologies and fully replaces the previous Excel spreadsheet format. Also, for your convenience, the 2014 data was carried forward from 2013. However, we would like to take the time and provide a one-on-one overview along with an accuracy check."

Based on valuable feedback from the EMD ECR Manager and the RPMs, along with experience gained by using the ECR Technologies Module, ITB proposed numerous process improvements within its first year of operation. Examples include:

Technologies Module:

- Added a link called "Description of Problem/Opportunity to be Addressed" (open new "pop-up" text box/window) which calls up the "Description of Problem/Opportunity to be Addressed" textbox information in the "Edit Project" module.
- Same as above for adding a "Description of Technical Approach/Strategy" link.

- Renamed the “Additional Project Information” textbox to “Additional Description of Technologies.”
- Included a checkbox for Vapor Intrusion as a “Contamination Media.”
- Removed unused/unneeded textboxes.

Technologies Lists:

- “Use these two categories (bullets below) and bring in all of the subcategories instead.” In other words, only two pop-up windows, each lists all of the technologies from their appropriate subcategories, using:
    - Ground Water, Surface Water, and Leachate
    - Soil, Sediment, Bedrock and Sludge
- Alternate: consider one list for all technologies since the selected “Contamination Media” checkboxes already determine soil, groundwater, etc. Question to the NETS developers, would one pop-up list of all technologies be too long?
- Moved Air Sparging
    1. From: Soil, Sediment, Bedrock and Sludge -> “In Situ Physical/Chemical Treatment”
    2. To: Ground Water, Surface Water, and Leachate -> “In Situ Physical/Chemical Treatment”

Contaminants of Concern list:

- Added cyanide to COCs to the “Other” category
- Added to COCs: “SVOCs” to Undefined, “Pesticides” to Pesticides and “Metals” to Metals

Simplicity, intuitiveness and streamlining:

- Pop-ups – could create user-generated and unseen “pop-unders.” However, these could be used for informational purposes (call up as needed).

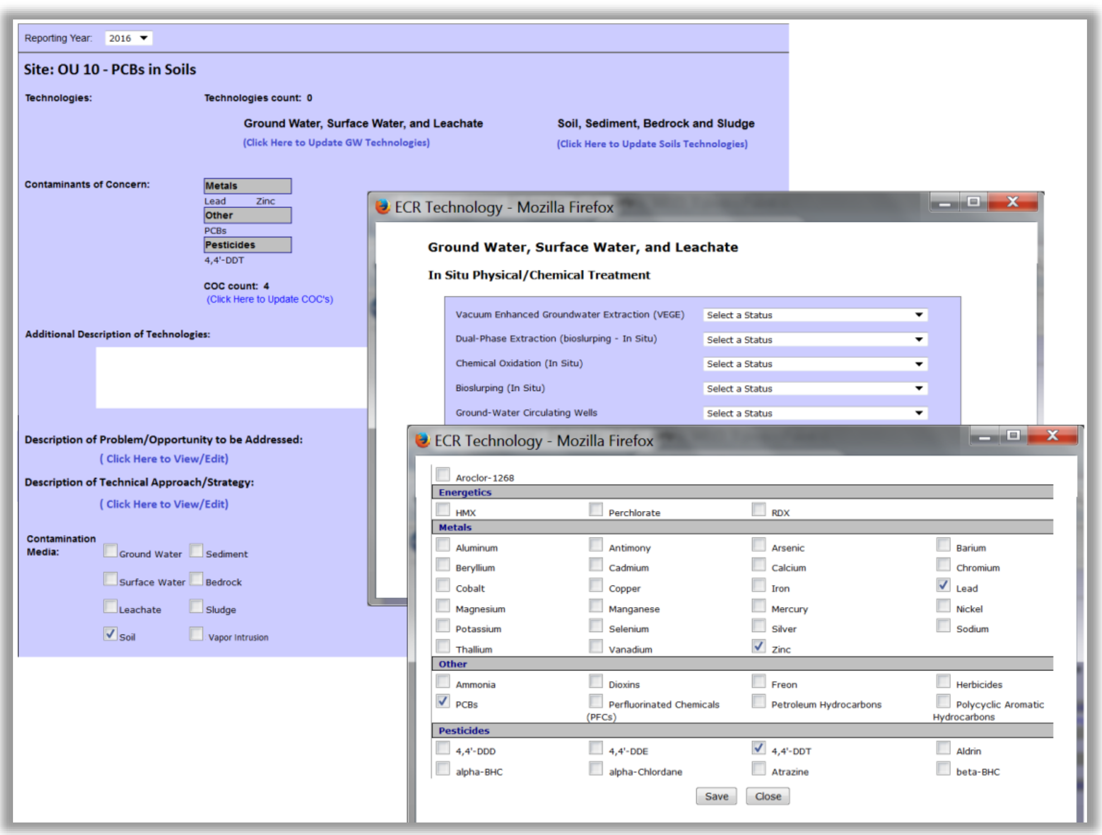

Figure 6 ECR Technologies Module as of June 2017

Path Forward for the NETS ECR Technologies Module

Recommendations for further evolution of the module:

- Improve search functionality – query and output into a webpage format instead of "download & open"
- Data-mine for cost analysis and trends as they apply to Centers/CFs technology expenditures, including "time to clean-up"
- Include at checkbox (yes or no) for remediation-specific assessments for climate change and/or catastrophic events

SSC – Comprehensive Overview of Accomplishments to Date (since May 2010)

Comprehensive list of remediation technologies introduced and demonstrated since May 2010	**Year Introduced (& Demonstrated)**
A demonstration of an in situ real time sensor capable of detecting and quantifying VOCs in groundwater.	2011 (Sep. – Nov. 2011) Sensor development by Oak Ridge National Laboratory.
In situ chemical oxidation (ISCO). (Pilot test at SSC.) Based on this success, SSC expanded the ISCO contractor's (EN Rx, Inc.) activities to full-scale implementation at cleanup Area G.	2011 (Mar. - Jul. 2012)
A pilot test of a new biostimulation product developed by BioStryke Remediation was started at SSC Area D.	2012 (Aug. 2013 –Jun. 2014)
HDD - Demonstration of a newly-developed horizontal directional drilling technology – ITB identified an innovative site characterization and remediation technology to address subsurface contamination at SSC. The technology—a combination of multiport groundwater sampling and remedial reagent injection well—is being demonstrated on an area of contaminated groundwater at SSC.	2013 (July 2014 – present) (ISCO Pilot ongoing)
Demonstration of High Resolution Site Characterization – This innovative approach to site assessments of VOCs in soil and groundwater uses a two-step process to better define contaminant plumes in areas that are not well characterized. The first step is a real-time sensor to provide continuous vertical data at a high density across a contaminated area. The key innovative feature is the data density—the probe is fast and provides continuous readout as it goes in depth, providing a clear picture of the location of subsurface contaminants. This is followed by the collection of field soil and groundwater samples	2013 (Sept. 2014) EPA Definition: High-resolution site characterization (HRSC) strategies and techniques use scale-appropriate measurement and sample density to define contaminant distributions, and the physical context in which they reside, with greater certainty, supporting faster and more effective site cleanup.

and laboratory analysis for quantification. The primary benefit of this approach is better assessment of the contaminant plume, leading to a better chance of a successful remediation.	
The requested $250K was given to SSC to do all the work that ITB coordinated. This includes: • EN Rx assessments at Area F, G, & C • The High Res Site Characterization proposed by Geosyntec at Area B.	2014 - Ongoing
Bldg. 2413/Area D Conduct Risk-Based Closure (RBC)	2015 – Ongoing Site selected, analysis completed (site qualifies for RBC) and funding awarded to complete the closure process.

Innovative site characterization technologies - Hyperspectral Imaging (continued from 2013)

Hyperspectral Imagery allows for the classification, identification, and detection of vegetation phenomena that relate to a wide range of applications to include: species identification, insect and disease detection/monitoring, fire risk analysis, stress detection, geobotanical analysis for oil/gas exploration, invasive species mapping (terrestrial and sub aquatic), crop residue, soil quality/tillage, vegetative health, precision agriculture and seed stock tracking. [SpecTIR Hyperspectral Imaging and Geospatial Solutions]

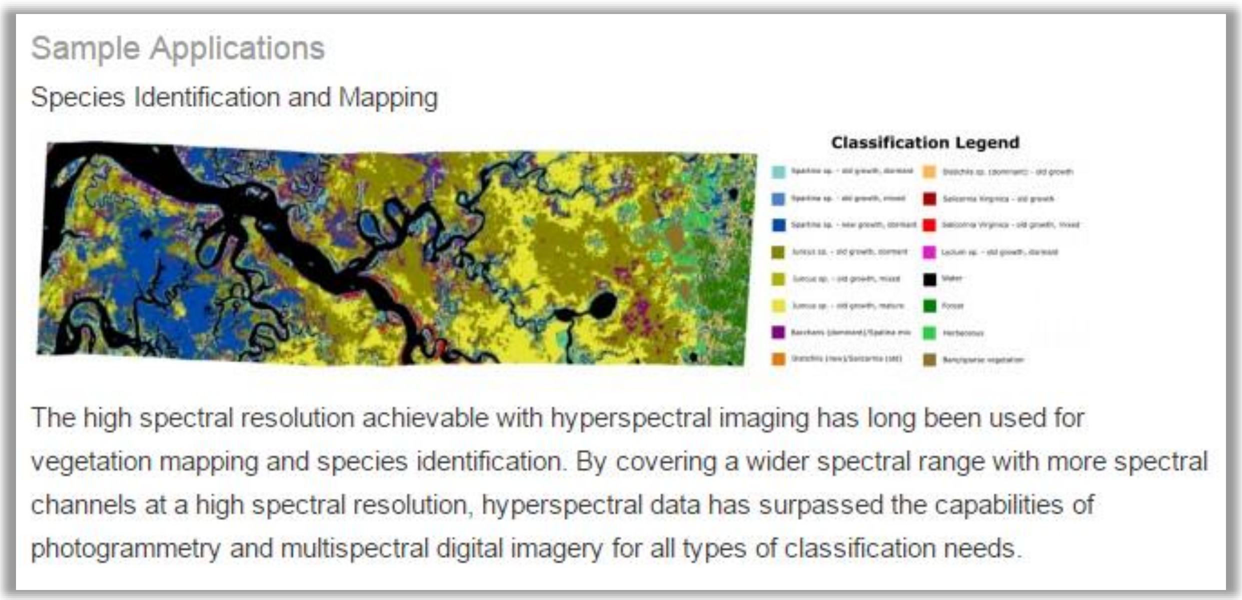

Figure 7 Example of HSI Species Mapping

The capability exists for conducting environmental assessments of TCE in groundwater using Hyperspectral Imaging (HSI), primarily through vegetative markers. In addition to MSFC's ground-based HSI environmental assessment technology, space-based and UAV platforms are available as well.

Worth noting, space-based HSI can provide fast (some in near real-time) and broader *initial* coverage at lower-cost when compared to the traditional (i.e. terrestrial) environmental site assessments.

This technology, HSI as a tool for environmental assessments, was presented at the TEERM/ITB PMR (January 13, 2015). In addition, the EMD Director suggested/queried about whether GIS can be included as well (MSFC is a focal point for NASA's GIS program).[10]

It's quite possible that Hyperspectral imagery from various sources (e.g. ISS, ESA and other earth observation satellites) could be collected and processed, then filtered into useable data (excludes cloud cover, etc.).

Technology Integration from previous NASA efforts:

- MSFC submitted a proposal to conduct HSI from the ISS (not selected at this time).
- ITB worked with KSC and SSC to identify groundwater plumes large enough to be imaged from space. The proposal also included activities to image disasters, lake water quality, point source pollution, crops, river discharge, coral reef, coastal ocean.
- Collaboration with KSC's Life Sciences Division: use HSI to image plants grown aboard the ISS. HSI would monitor health status and stressors of onboard crops before it is visible and causes damage to the plant. In addition, develop a protocol to stop the stress; hence, protecting this food source for astronauts.

Airborne Hyperspectral Imaging Systems – Resonon

Resonon's airborne systems are completely integrated turnkey solutions, with all hardware and software necessary to acquire georegistered hyperspectral data.

Airborne systems can be mounted on both un-manned and manned aerial platforms.

UAV discussions

As an assessment platform, airborne (UAV) imaging is advancing very quickly and ITB looked for opportunities there as well.

Agency-wide Plant Species Database to Support Hyperspectral Imaging

During the HSI presentation at the 2015 RPM Meeting, the need to identify, select and database the different species of plants was presented. In anticipation of HSI assessments for TCE across the NASA Centers, ITB inquired as to whether an Agency-wide species database was already developed. As it is now known, none exist other than the tree-type species tested in the HSI Lab at MSFC. However, these tree samples (maple, sycamore, willow, and sweet gum) were selected from contaminated springs at MSFC.

The primary goal is to have a pre-identified Agency-wide vegetative species to support spectral analysis for future studies both in the lab and field.

Based on ITB's suggestion, the SME at MSFC became interested in a database of Center/CF specific plant species, including their spectral analysis. Initially, ITB would also conduct a literary review of previous ecological studies to include any phytoremediation efforts. For qualitative analysis afterwards, some field and lab work could be necessary. It is worth noting that graduate students at MSFC are conducting the spectral imaging in the lab already.

Trees	Laurel Oak*	Water Oak* (few)	Black Gum*	Sweet Bay*	Sweet Gum**

[10] GIS and imaging - Enables a common environment for integrating data from multi-phenomenology imaging systems.

Trees	Loblolly Pine***	Red Maple	Slash Pine	Yellow Poplar	American Holly
Trees	Titi Tree	Black Cherry	Long Leaf Pine		
Shrubs	Greenbrier	American Holly	Gallberry	Blackberry (Bramble)	Dog Fennel
Vines	Greenbrier	Trumpet Creeper	Muscadine	Poison Ivy	
Invasive	Chinese Tallow				

Figure 8 Foliage for Area B at SSC (Thanks goes to Craig Case, U.S. Army)

*- indicates upper canopy, **- indicates mid & upper canopy, ***- indicates 70% of upper canopy

In addition, ITB regularly provided concise technology and funding/project opportunity information to MSFC.

Hyperspectral project opportunity at GSFC

An old TCE plume at GSFC is being re-assessed. The area of concern is classified as "voluntary clean-up" as per the State regulators, although NASA is taking a pro-active approach considering the risk of the plume migrating off-site. Also, the area is mostly undeveloped and covered with vegetation, i.e. conducive for hyperspectral imaging.

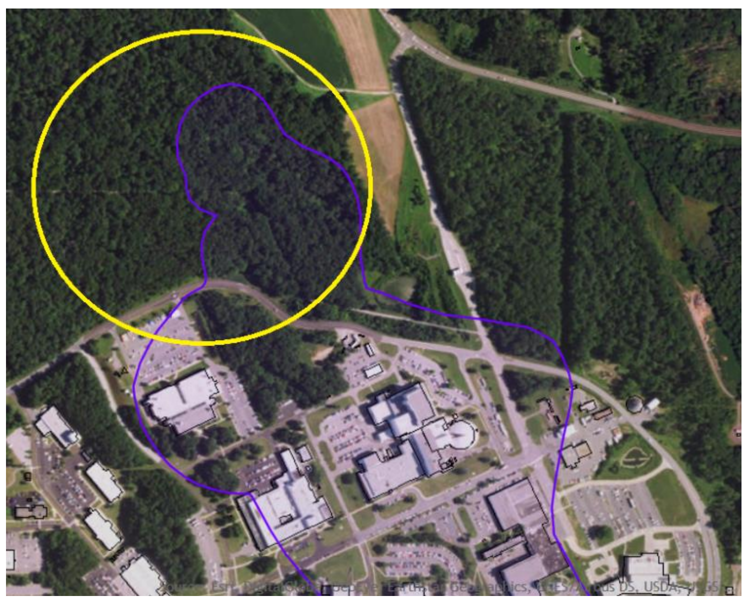

Figure 9 Potential Hyperspectral Imaging Area - TCE Plume at GSFC

A first step for this HSI opportunity is knowing the specific signatures of the vegetation at GSFC (see Figure 8, area circled in yellow), in this case:

Upland forests are characterized by pine and hardwoods, while floodplain forests are characterized by swamp forest that includes oaks (Quercus spp), maples (Acer spp), Sweetgum (Liquidambar stryaciflua), American Sycamore (Platanus occidentalis), and American Beech (Fagus grandifolia).

ITB conferred with the HSI SME at MSFC to determine if an assessment at GSFC aligns with their on-going research. At the time of this report, interest was high but a definitive answer had not been received.

Vapor Intrusion Detection and Mitigation

On September 28, 2011, the U.S. Environmental Protection Agency (EPA) released its long-awaited final health assessment (Assessment) for trichloroethylene (TCE). Unlike EPA's prior classification of TCE as a probable human carcinogen, EPA now is classifying TCE as carcinogenic to humans through all routes of exposure. The

Assessment also establishes health benchmarks for non-cancer effects by the oral and inhalation routes of exposure.

Though likely it will take years for EPA to promulgate new enforceable standards that rely upon the new Assessment, many impacts of the Assessment will manifest sooner. For example, it is expected that the revised TCE values likely will be used on an ad hoc basis in regional EPA offices. For example, EPA Region 9 recently stated that it may announce changes to the regional screening levels, non-binding tools for screening preliminary soil or groundwater levels at contaminated sites, to reflect the new TCE exposure recommendations as early as May 2012.

The Air Force Environment Chief Terry Yonkers noted in a November 29, 2011, speech that the Air Force could face up to $15 billion in added cleanup costs if EPA modifies the groundwater standards for TCE based on the Assessment.

The Use & Remediation of TCE at NASA – Primary COC Risk Factor for VI

TCE is a chemical that has been used commercially in the United States since the 1920s, and by NASA since the 1950s for degreasing and cleaning of metal parts in early rocket engine testing and aircraft maintenance. NASA has since modified these processes to reduce the use of TCE and is addressing TCE contamination that remains from historical use. To read more about TCE-specific cleanup efforts, and NASA's research with identifying substitutes, click here.

> "You have the new US EPA VI guides, updated ASTM Phase I ESA Standard, US EPA rulemaking on the AAI rule saying vapor is part of a Phase I, and new a TCE threshold that is dramatically lower concentrations."[11]

VI Potential at MAF

By volatilizing toxic chemicals into unsaturated soil pore space air, possibly beneath occupied structures, ISTD could potentially increase the chances of vapor intrusion (VI) becoming an issue at MAF and it is ITB's opinion that assessment and mitigation (if required) of VI are always important considerations to protect occupants. The pursuit of opportunities to demonstrate and evaluate innovative VI detection and mitigation technologies at MAF is ongoing and has potential collaborative tie-ins with Ames Research Center (ARC) as they strive to address their potential VI issues. However, the sheer size of MAF's Building 103, under which DNAPL TCE is reportedly present, combined with the types of activities that occur within Building 103 (e.g. motor vehicles are driven inside) present significant complications to the assessment of VI that would have to be overcome.

Real-time sensors for vapor intrusion detection

Indoor air quality concerns created by contaminated soil and groundwater – Contaminant sensor networks and technologies can be used to detect known and new contaminants of concern.

- Real-Time Continuous Monitoring of TCE & other VOCs in Indoor Air from Hartman Environmental Geoscience. Several relatively low cost PIDs were deployed in a building with readings tracked every 15 minutes or so. The current detection capabilities are on the order of 5ppb, but a new version currently being tested can get down to 1ppb (with hopes of getting to 0.5ppb by Fall).

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[11] The TCE Revolution: Why New Toxicity Values Will Result in More Sites Getting "Caught in the Net"

EPA Releases Vapor Intrusion Screening Level Calculator

The Vapor Intrusion Screening Level (VISL) Calculator is a spreadsheet tool that:

1. Lists chemicals considered to be volatile and known to pose a potential cancer risk or non-cancer hazard through the inhalation pathway;
2. Provides generally recommended screening-level concentrations for groundwater, soil gas (exterior to buildings and sub-slab) and indoor air for default target risk levels and exposure scenarios; and
3. Allows calculation of site-specific screening levels based on user-defined target risk levels and exposure scenarios.

The VISL Calculator can assist Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) remedial project managers (RPMs) and on-scene coordinators (OSCs), as well as Resource Conservation and Recovery Act (RCRA) project managers in determining whether the vapor intrusion (VI) pathway has the potential to pose an unacceptable level of risk to human health by:

1. Identifying whether chemicals that can pose a risk through VI are present;
2. Determining if those chemicals are present at explosive levels; and
3. Comparing subsurface or indoor data against screening levels provided in the Calculator.

The screening level concentrations in the Calculator are not intended to be used as cleanup levels, nor are they intended to supersede existing criteria of the lead regulatory authority

- EPA Releases Vapor Intrusion Screening Level Calculator
- Vapor Intrusion Screening Level (VISL) Calculator – User's Guide

Availability of Vapor Intrusion (VI) Guidance from the EPA

Two technical guides to support assessment and mitigation activities at sites where vapor intrusion is a current or potential concern are available for download from the EPA.

- "Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air"- Intended for use at sites being evaluated by the EPA pursuant to CERCLA or corrective action provisions of RCRA.
- "Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites"- Intended for use at sites subject to petroleum contamination from USTs.

Both guides apply to residential and non-residential structures. Additional information is available on EPA's website.

ITB followed VI technologies (development and demonstrations)

- Technology that monitors for methane, tVOCs, specific VOCs, barometric pressure, etc.
- A currently deployed system that measures TCE and other VOCs (Benzene, PCE, CCl_4, etc.) at very low levels using an automated GC that is multiplexed to allow for sampling/analysis from up to 14 locations within a building (or from multiple buildings) per system. Setup includes data mapping/visualization and an automated alerting function when concentration thresholds are exceeded.
- Integrated visualization platform with entities that deploy sub-slab depressurization (SSD) systems e.g. mapping pressure, pressure gradient, and concentration for performance verification.

NASA GSFC TCE Groundwater Plume (RTCD 2016)

ITBs was asked to assist with supporting… "GSFC, Greenbelt MD, has a TCE Plume. The plume stretches thousands of feet across the Center and is currently threatening to migrate off Center."

ITB conducted an assessment with the objective towards optimization included data-supported suggestions and recommendations for alternative or potential enhancements to existing remediation activities and strategies at Greenbelt.

The GSFC TCE Plume extends through the middle of the Center, from the northern boundary to the southern boundary of the Center. The Plume poses a low risk to Center employees and off site residential receptors because the depth to groundwater is greater than 70 ft. There is available potable water; the aquifer is not used for drinking water and no vapor intrusion has been detected. A Land Use Control Implementation Plan (LUCIP) was completed in 2015. The Maryland Department of the Environment (MDE) considers the site NFA as long as LUC controls are in place and the TCE plume remains stable and within GSFC boundaries.

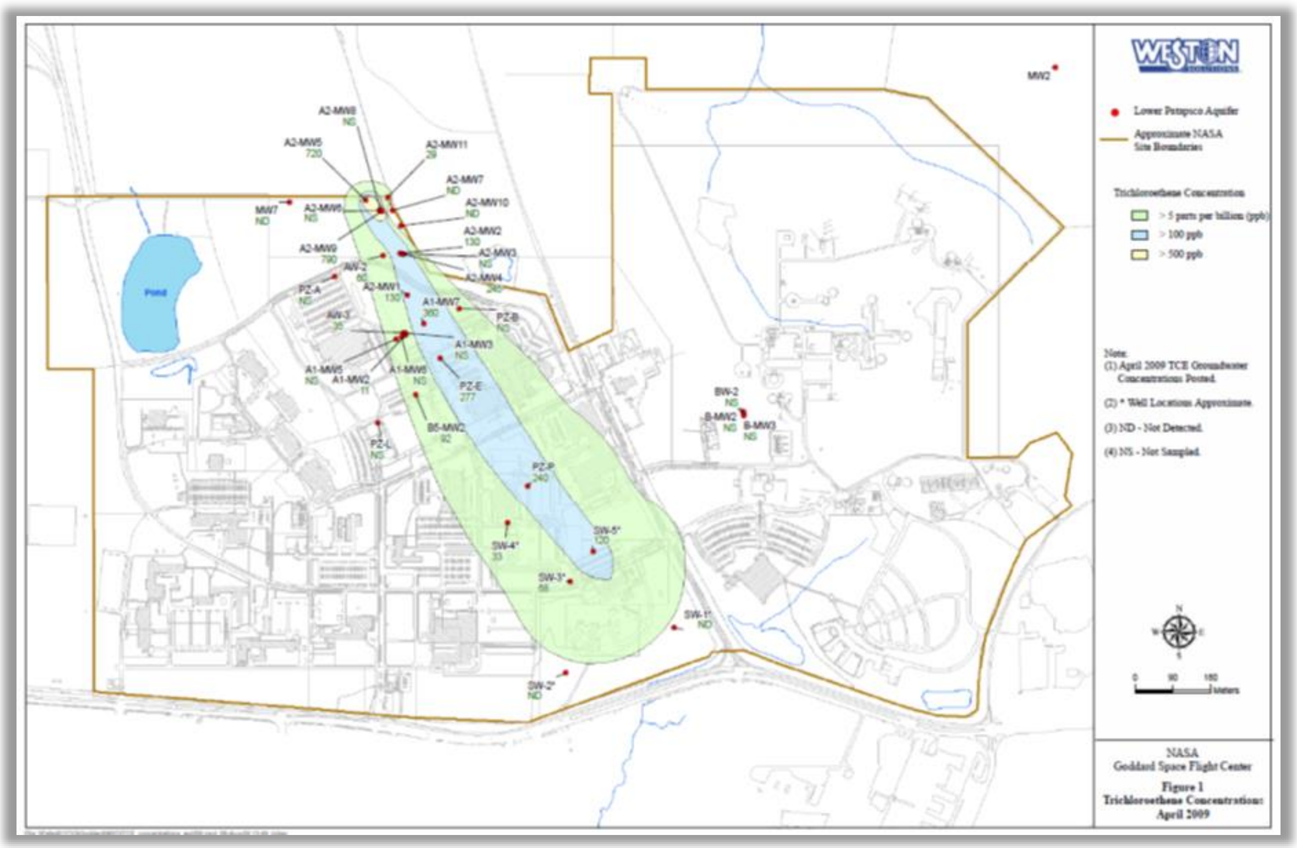

Figure 10 TCE Plume - GSFC (Greenbelt)

Long Term Monitoring and LUC inspections per the LUCIP includes Natural Attenuation, with periodic groundwater monitoring. Clean-up requirement status is "Voluntary."

In 2014, monitoring showed an increase in TCE concentration at the sentry wells. New monitoring wells installed at the fence line detected TCE. A pilot study is planned to evaluate whether additional actions should be implemented to ensure TCE plume remains with GFSC boundary. Following the pilot study, two additional rounds of injections are planned to optimize the TCE plume attenuation.

Important Notes:

- GSFC is in the Atlantic Coastal Plains. The geology is sand with clay/silt lenses and groundwater is about 30 feet bgs at the source area and 100 feet bgs everywhere else.
- Highest TCE concentration at the source area is about 1,600 µg/L and the distance from there to the property boundary is about 1 mile.
- No DNAPL. Low permeability lenses may be acting as a continuing source.
- There is a residential development and schools across the street from GSFC. All residents and facilities are on municipal water so there is no exposure to groundwater, but VI could be a concern.

In addition to long term monitoring and land use controls, several risk mitigation approaches were considered, including:

- En Rx as a potential groundwater source area treatment option.
- Biostryke's enhanced bioremediation product for the dilute plume and help stop it from migrating off site. ITB coordinated a pilot at SSC using Biostryke and it worked well.
- PlumeStop™ Liquid Activated Carbon™ and ORC Advanced® applied on-site.

Based on ITB's assessment, some areas in the vicinity of this site had not been fully characterized. Initially, a more detailed stratigraphic profiling could assist in understanding the aquifer system sand bodies' geometry as an integrated hydrologic system and enhance potential active remediation strategies and subsequent efficiencies.

ITB recommended:

1. Detailed Site Characterization and Stratigraphic Interpretation by AECOM - Environmental Sequence Stratigraphy (ESS). ESS provides the ability to visualize the subsurface in much greater detail and helps develop contaminated groundwater modeling that should provide more effective remedial strategies and outcomes. Existing data can be used to better understand and more accurately detail subsurface conditions.
2. Geophysical logging within the existing monitor wells for stratigraphic correlation. Geophysical logs include natural gamma in cased wells and spontaneous potential, multi-point resistivity and single-point resistance, where appropriate. Gamma radiation generally, is higher in clays and silts, and lower in sands and gravels; resistivity and resistance generally are lower in clays and silts, and higher in sands and gravels.

Environmental Sequence Stratigraphy (ESS). The most common reason for failure of a groundwater remediation project is an inadequate understanding of subsurface contaminant transport pathways. Our geologic experts apply AECOM's proprietary ESS methods to construct an accurate, geologically defensible three-dimensional hydrostratigraphic framework. We apply ESS methods and detailed knowledge of depositional systems to reduce the uncertainty of the subsurface and improve remediation design and outcome.

For characterization optimization, Environmental Sequence Stratigraphy (ESS) was evaluated and deemed a "perfect fit", but ultimately rejected by the RPM due to the relative simplicity of the existing site. However, the ESS evaluation process as applied to the Greenbelt site enabled the RPM to gain additional insight regarding the site's stratigraphy.

UPDATE: The ESS team has left AECOM and moved to Burns and McDonnell.

While the current technology is Monitored Natural Attenuation (MNA) with LTM, chemical oxidation is being considered to prevent the plume from migrating off-site.

"In addition to the recommendation that LTM continue at the site, along with associated statistical analysis updates, it is recommended that an optimization and enhancement study be considered to address increasing TCE trends along the western extent, eastern extent, and southern portion of the TCE plume." [12]

For detailed information on suggested alternative technologies, please see the document titled ***DRAFT - Alternative Remediation Technologies for NASA GSFC at Greenbelt.docx (Appendix 9c).***

Agency-wide Analysis of Industrial Control Systems (ICS) that Support Cleanup Operations

As per NASA's Task Order NNH15CN32D, paragraph 2.2.9; ITB conducted an Agency-wide analysis of Industrial Control Systems (ICS) that support environmental cleanup operations. The primary objective of this study was to analyze the vulnerabilities of NASA Centers and CFs related to all groundwater treatment systems and supporting infrastructure that utilize ICS. The graphic below represents the process developed by ITB for this task. Each step of the process produced a product or tool that enabled ITB to effectively assess the enormous amount of information accumulated during this task order.

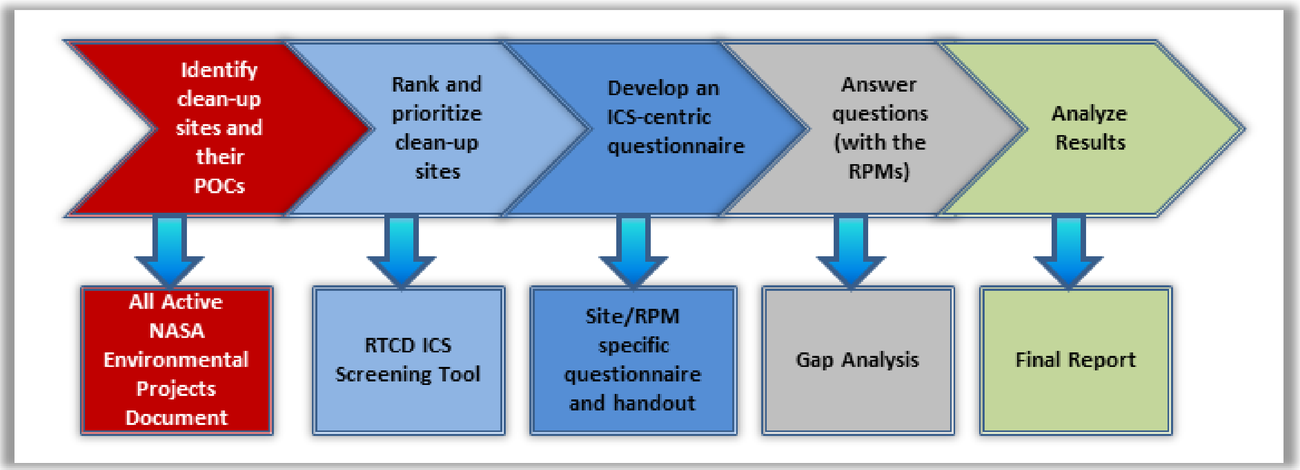

Figure 11 ITB's ICS Assessment Process

NOTE: The ICS report is sensitive in nature and was submitted separately (and previously).

6. Process Improvements, Sustainable Remediation and Energy Conservation/Reduction at Clean-up Sites

Risk-Based Closure

"Remediation is also focused on determining whether cleanup of soil and groundwater is even necessary, so long as the levels of contamination do not pose a risk to human health or the environment."[13]

A lingering question often remains unanswered, "Why are we spending so much money on environmental cleanup when there's no apparent risk?"

For ITB, many of NASA's UEL sites (e.g. cleanup sites that have low priorities due to lower risks) presented a different challenge, i.e. "How do we reduce costs and time to cleanup when certain low-risk sites remain unfunded for

[12] NASA GSFC TCE Groundwater Plume: Final 2015 Groundwater Long-Term Monitoring Report - Straughan Environmental, January 2016

[13] Risk Based Cleanup: What Is It and Is It Right For Your Situation? Steve Henshaw, June 2012

remediation?" However, these same sites already require a significant amount of Long-Term Management (LTM) costs (e.g. groundwater sampling, site monitoring/reporting, labor rates, etc.). In addition, many of these sites incorporate Land Use Controls that include "no public access" to the site and/or facility. The "technology" for these sites is primarily Monitored Natural Attenuation (NA).

A thorough investigation into regulatory requirements for LTM (Federal and State), reviewing advanced concepts of LTM (e.g. "Minding the End" and the EPA's Long-Term Monitoring Optimization guidance) along with recent trends in regulatory acceptance, prompted ITB to pursue opportunities for Risk-Based Closure.

SESSION LAW 2011-186
HOUSE BILL 45

AN ACT TO ALLOW THE USE OF RISK-BASED REMEDIATION TO ACCELERATE THE CLEANUP OF CONTAMINATED INDUSTRIAL SITES FOR THE PURPOSE OF LIMITING HUMAN AND ENVIRONMENTAL EXPOSURE TO SAFE LEVELS, TO PROTECT CURRENT AND LIKELY FUTURE USES OF GROUNDWATER, AND TO ENSURE THE COST-EFFECTIVE APPLICATION OF LIMITED PUBLIC AND PRIVATE RESOURCES.

Figure 12 Session Law 2011-186 House Bill 45 - General Assembly of North Carolina

> "§ 130A-310.66. Purpose.
>
> It is the purpose of this Part to authorize the Department to approve the remediation of contaminated industrial sites based on site-specific remediation standards in circumstances where site-specific remediation standards are adequate to protect public health, safety, and welfare and the environment and are consistent with protection of current and anticipated future use of groundwater and surface water affected or potentially affected by the contamination.[14]

ITB collaborates on the feasibility of RBC with AECOM

Risk based corrective actions and risk based closures involve a process of considering appropriate site-specific data to adequately define the nature and extent of contamination and its associated risk; select closure options; and determine the necessity for response action services based on the current and projected land uses at the site. Beginning in the 1980s and as recently as 2015, EPA has issued several guidance documents regarding risk assessment, risk based closure, and risk assessment for informed decision making.

Through the remedial investigation/feasibility study (RI/FS) process, baseline risk assessments are typically performed to assess actual or potential threats to human health or the environment, and to determine whether remedial action is warranted. For most sites managed under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA), the site decision documents and remediation goals were historically established based on upper-bound risk estimates. Site restoration was required to levels that would allow for unrestricted use (i.e. residential land use conditions) unless technically impractical. *The risk based corrective action and closure process now provides for greater latitude.*

Subsequently, many CERCLA sites have been transferred to state-led cleanup. Additionally, supplemental guidance and updates on risk assessment procedures, including state-specific risk based closure guidance

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[14] Session Law 2011-186 House Bill 45 - General Assembly of North Carolina

(Florida, Mississippi, Virginia among others); have been issued within the past 10 years. These guidance and procedure documents clarify the risk management options available that allow for site closure through the use of site specific data for calculation of alternate target levels, use of statistical methods to meet target levels or calculate site-specific target levels, and the use of institutional and/or engineering controls (ICs / ECs) to eliminate exposure pathways or to remediate to alternate cleanup targets consistent with potential risk under the current and projected land use.

Specifically, EPA has published several guidance documents on the use of various controls between 2000 and 2015. Guidance from EPA (9/2000) "Site Manager's Guide to Identifying, Evaluating and Selecting Institutional Controls (ICs) at Superfund and Resource Conservation and Recovery Act (RCRA) Corrective Action Cleanups" confirms that ICs are among the tools allowable under CERCLA and RCRA. EPA strategy specific to EPA management of ICs at Superfund sites is also discussed in the 9/2004 OSWER publication No 9355.0-106.

ITB, partnered with AECOM, proposed the selection of several sites at SSC, then reviewed and evaluated the existing risk assessment and decision documents. The site-specific evaluations focused on changes in risk guidance and applicable state risk-based closure procedures to determine if there are opportunities for risk reduction. Risk assessments were revisited and reviewed relative to current guidance or site-specific information that was previously unavailable. The evaluations included a determination of the key risk drivers and whether ICs can be used to eliminate, manage or mitigate exposure pathways. The objective of the evaluations were to identify opportunities to modify endpoints and expedite site closure.

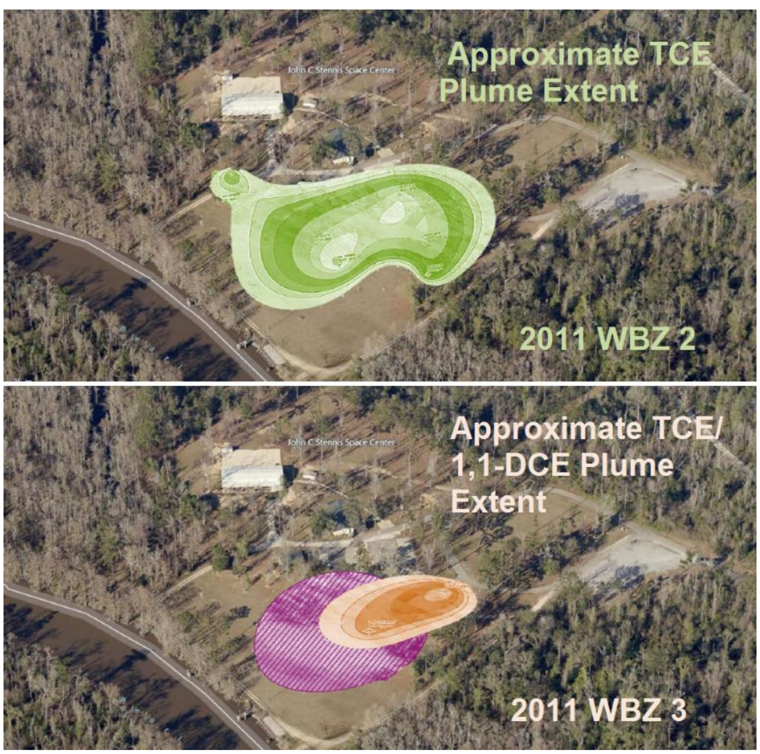

Figure 13 Water Bearing Zones 2 & 3 at SSC

Area D - Risked Based Closure Opportunity Analysis

ITB developed an RBC project opportunity in collaboration with SMEs at AECOM and the RPMs at SSC. Based on its knowledge and insight of the cleanup sites at SSC, ITB successfully:

- Recommended Area D as the most suitable site for RBC
- Negotiated with AECOM to provide the initial site analysis as an "In-Kind" service ($25,000 value)
- Consulted with the SSC RPMs on project contract award procedures ("for bid" or sole-source)
- Negotiated with AECOM on a price ceiling which includes actual award of site closure

On July 20, 2017, the RPM from SSC emailed, "Yes the RBC was approved and we are having a meeting with AECOM and MDEQ on 8/10 to get kicked off on the right foot."

Path Forward

By developing site-specific cleanup goals, and combining natural attenuation, source reduction, and land use controls, innovative risk-based closure plans could be implemented at many sites throughout NASA.

Performance-Based Contracting

Performance Based Contracting (PBC) is a contract and plan that allows payment to be based on performance and goals (milestones)

1. Goals are set for site specific needs
2. Liability is transferred onto the subcontractor
3. Milestones provide incentive for swiftness
4. Timeline is more consistent
5. Cash flow can occur more evenly

Key Point – PBR contracting helps reduce timelines and requires the subcontractor to perform but also requires reductions and site remediation to actually be occurring.

PBR is an alternative site closure strategy that sets a fixed ceiling on “cost-to-closure“ or some other appropriate remedial objective such as monitored natural attenuation concentration levels. Payment milestones must be reached for the contractor to invoice the customer. If certain predetermined progress points are not reached, the customer does not pay. PBR cleanup strategies are used successfully at Air Force sites and within the private sector as well.

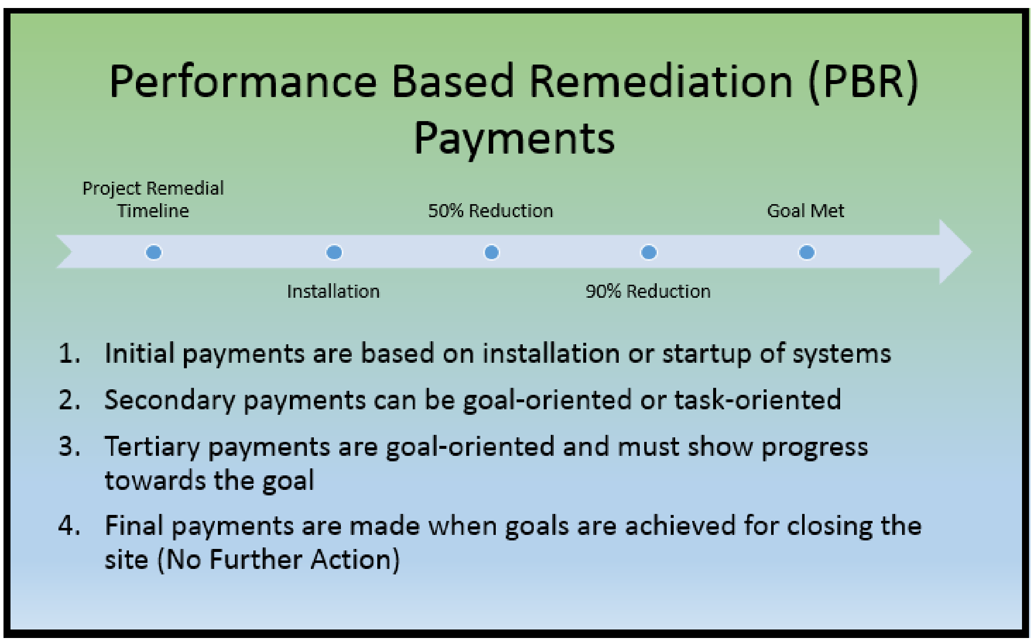

Figure 14 Example of PBR Payment System

ITB suggested and advocated PBR for a few specific sites at Stennis Space Center (SSC), who ultimately accepted two PBR proposals.

PBR can benefit SSC by potentially reducing the time to site closure of Areas C, F, and G by decades and potentially reducing the cost to close these areas by hundreds of thousands of dollars. It should be noted that current groundwater pump and treat systems at these sites are not expected to achieve closure objectives for at least 30 years. Other NASA Centers may benefit from SSC’s PBR experience and application and/or implementation of this management strategy as well. ***For detailed information please see Appendix 9b - PBR and PBC at SSC - EN Rx.pdf.***

Green & Sustainable Remediation (GSR)

For 2015, ITB proposed the advancement of GSR projects and programs within NASA as a top priority. For example:

- The continuation of GSR webinars for the RPMs
- The pursuit of a mechanism to facilitate the open and free exchange of ideas and concerns between RPMs and HQ regarding GSR
- The identification of track-able GSR metrics and the potential implementation of a GSR dashboard where Centers and CFs can measure their progress from baseline data towards established GSR goals

The U.S. Environmental Protection Agency (EPA) defines green remediation as the practice of considering all environmental effects of remedy implementation and incorporating options to minimize the environmental footprint of cleanup actions. Green remediation strategies can include a detailed analysis in which components of a remedy are closely examined and large contributions to the footprint are identified. More effective steps can then be taken to reduce the footprint while meeting regulatory requirements driving the cleanup.[15]

The EPA's methodology for Greener Cleanups is just one of the many GSR tools that were employed throughout the RTCD. Others were:

- NASA's own Green Remediation Team
- U.S. Air Force Sustainable Remediation Tool (SRT)
- SiteWise™ GSR Tool (jointly developed by Battelle, US Navy, and USACE)
- ITRC Green and Sustainable Remediation
- EPA Methodology & Spreadsheets for Environmental Analysis (SEFA)

Methodology & Spreadsheets for Environmental Footprint Analysis (SEFA)

ITB had on-going interests in gaining an in-depth understanding of and potentially implementing the Spreadsheets for Environmental Footprint Analysis (SEFA), and proposing a comparison to other tools as well. For example, SiteWise (US Navy & USACE), the Sustainable Remediation Tool (SRT - USAF) and the DTSC's Green Remediation Evaluation Matrix, or GREM.

The EPA developed a set of analytical workbooks known as "SEFA" (Spreadsheets for Environmental Footprint Analysis) assists the user in estimating the footprint metrics established in the methodology.

EPA's set of green remediation metrics corresponds with the five core elements of a greener cleanup and may be measured in distinct quantitative units. Each metric represents a parameter that a project team likely has the ability to change when planning and implementing a cleanup in order to achieve a smaller environmental footprint.

Quantification Process in the Methodology	
Step 1:	Set goals and scope of analysis
Step 2:	Gather remedy information
Step 3:	Quantify onsite materials and waste metrics
Step 4:	Quantify onsite water metrics
Step 5:	Quantify energy and air metrics
Step 6:	Qualitatively describe affected ecosystem services
Step 7:	Present results

Figure 15 SEFA Quantification Process

[15] EPA's Methodology for Understanding and Reducing a Project's Environmental Footprint - Feb 2012

Climate Change Adaptation and Resiliency for Clean-up Sites

While planning for the LaRC five year review with the ECR Manager at NASA HQ, ITB didn't see any references to climate change, specifically in regards to remediation. In other words, how and where can the potential effects of climate change impact the current and future clean-up sites? For example, an increased risk at LaRC would be from tidal surges and "100 year flood" type scenarios.

With that in mind, ITB proposed an assessment of NASA's clean-up sites in regards to Climate Change. EMD agreed (and gave a green light to proceed) in that it would be useful to see what effect climate change would have. It was also noted that these assessments had not been conducted from an Agency perspective/initiative.

Note: while looking at NASA's [2013] and [2014] Climate Risk Management Plans there was only one reference to remediation (2014):

> **Natural systems** – Impacts to threatened and endangered species at NASA Centers may require additional or different management. The increasing possibility of wildfires puts natural and built systems at risk. Wetland losses due to increased storm surge impacts may affect the buffering effect that protects some of our coastal facilities. Increasing downpours and fluctuating groundwater tables may mobilize contaminants at remediation sites.

The following chart from the 2014 Plan describes the hazards and impacts that would apply to clean-up sites as well.

Figure 1. Key Climate Hazards and Potential Impacts to NASA Assets and Capabilities

Key Climate Hazards	Potential Impacts
More frequent and extreme high temperatures and humidity	Increased risk of heat-related ailments among outdoor workers; higher cooling costs; decreased utility reliability; damage to buildings
More frequent and intense droughts, seasonal shifts in water cycle	Reduced water availability; higher water costs; salt water intrusion; ground water changes
More intense precipitation events	More frequent flooding of low-lying indoor and outdoor areas
Sea level rise	Loss of usable land; inundation of coastal ecosystems
More frequent and intense coastal flood events	Coastal erosion; safety implications for surrounding communities

Table 4 Climate Hazards and Impacts

Also, Goal #9 - Climate Change Resilience (CCR), of the 2014 Strategic Sustainability Performance Plan has details that are fairly generic e.g. no specific remediation topics.

Goal 9: Climate Change Resilience

GOAL: Evaluate climate change risks to identify and manage the effects of climate change on the agency's operations and mission in both the short and long term

Status as of September 30, 2013	• Six of NASA's coastal facilities had hosted multi-day climate adaptation workshops • Cosponsoring/facilitating DC-area climate adaptation series with federal and non-federal neighbors. • Quarterly Center Sustainability Officer meetings include climate adaptation progress as an agenda item • NASA is incorporating climate change factors into its sustainable facilities design program and its master planning policies

Figure 16 Goal 9 - Climate Change Resilience

To recap, NASA has *not* conducted remediation-specific climate change assessments (ITB suggests adding a yes or no checkbox in NETS as a minimum).

ITB's Proposed Action (CCR Assessment Phase 1):

- Obtain or develop a remediation (site-specific) Climate Change Adaptation/Resilience questionnaire
- Query the RPMs to determine their level of awareness and program planning
- Provide analysis and rank according to risk (sensitive receptors, post-event equipment repairs, etc.)

ITB's Proposed Action (CCR Assessment Phase 2):

- Conduct CCR Assessments as necessary across the Agency
- Report on findings and provide recommendations

Incidentally, LaRC has recently partnered with the local utility companies for a study on climate change from an infrastructure perspective.

- Langley Research Center Utility Risk from Future Climate Change

SSC ISCO demonstration as an example of Green Remediation

An ITB-initiated project demonstrated that ISCO can be used to augment currently-deployed pump and treat technology to reduce the cost and time required to achieve groundwater remedial goals, including sustainability goals for NASA.

- The entire set up was completely self-contained and off-grid. The system was also automated and could be monitored remotely.
- The batteries to power the solenoid valves are recharged by an integrated solar panel.
- The system used standard public utility water (low pressure and low volume) to "push" the chemical into the aquifer.

WSTF Solar Photovoltaics (PV)

NASA HQ provided $4.6M to fund a NASA owned 1MW or more Solar PV installation near the WSTF groundwater treatment system area.

> "The goal of the project would be to use the renewable energy from the photovoltaic system to provide renewable energy for the operation of activities at WSTF such as the groundwater treatment system and general facility operations."

Installation of a PV solar power generation plant (approx. 1to 4MW) can supply renewable power to the Plumefront Groundwater Treatment System at WSTF. This system will reduce utility costs and improve power factor performance at WSTF, which are currently negatively affected by the Remediation System. The renewable energy system also can provide energy security for critical assets at WSTF.

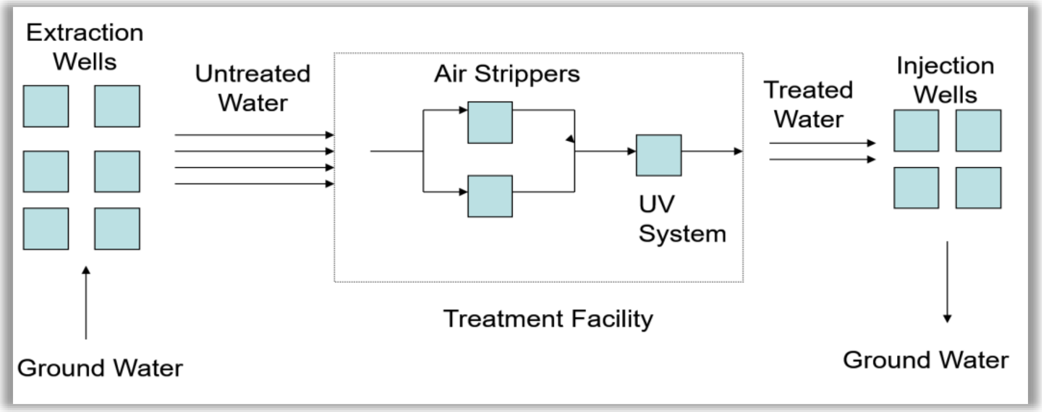

Figure 17 WSTF Plumefront Groundwater Treatment System

WSTF has completed an Environmental Assessment for the solar project and is working with the National Renewable Energy Laboratory (NREL) to perform a feasibility study which includes; identifying the site's location, size, and technologies for the project. WSTF hosted an industry day along with issuing a Request for Information (RFI) as a method for information exchange from companies that are interested in the project. The EPA expressed interest in a feasibility study specifically focusing on generating renewable energy to supply the water treatment facility, and offered funding assistance as well. Preliminary studies have been performed and a 1-4 MW system can be design/built as soon as funding is provided.

7. Notable Reports/Papers

SSFL Summary Report – March 25, 2011 (as part of the Initial RTCD TO – PH 2)

Shortly after Phase 2 kick-off, EMD asked ITB to prepare a document that could potentially lead to a partnership opportunity. It was EMD's understanding that U.S. Army Installation Management Command (IMCOM) – Europe had contemplated conducting pilot-testing of In-Situ Chemical Oxidation (ISCO) to remediate TCE from groundwater in fractured sandstone at U.S. Army Garrison in Kaiserslautern, Germany. NASA was also pursuing ISCO, among other techniques, as a potential remedial option for TCE-impacted groundwater at the SSFL, in Ventura County, California.

Based on the shared geology and primary contaminant of concern, it was NASA's opinion that open dialogue and shared information could lead to greater mutual success in remediation. Therefore, EMD requested that the RTCD team prepare a report summarizing the nature and extent of TCE-impacted groundwater at SSFL. EMD anticipated that the transmission of this Summary Report to point of contacts (POCs) at IMCOM would serve as a first step towards forging a working collaborative relationship for future remedial efforts conducted at SSFL and U.S Army Garrison, Kaiserslautern.

ITB prepared a 21-page SSFL Summary Report that was submitted to EMD on March 25, 2011. This report presented an overview of NASA's portions of SSFL. More specifically, this document intended to present the reader with preliminary information regarding the historical and geographical context, assessment, and potential environmental remediation of TCE from groundwater in fractured sandstone bedrock similar to that found beneath the U.S. Army Garrison Kaiserslautern. This paper was distributed by EMD to IMCOM POCs in April 2011. The pursuit of a collaborative effort between NASA and IMCOM continues.

The transmission of ITB's 2011 introductory SSFL summary document to U.S. Army Installation Management Command (IMCOM) as part of RTCD Phase 2 resulted in the sharing of the initial results of a 2011 ISCO pilot test conducted at Kaiserslautern Army Depot (KAD), Germany. NASA was also pursuing ISCO, among other strategies, as a potential remedial option for groundwater at SSFL and the efforts of IMCOM will be helpful to leverage NASA's efforts. The Interim Report for the ISCO Pilot Study, Building 2288 Site, KAD was provided to ITB in August 2012 for review and comment. ITB provided comments to NASA by email on September 18, 2012.

See Appendix 3b - SUMMARY Santa Susana Field Laboratory-v5a.pdf

SSC Summary Report – June 13, 2011 (as part of the Initial RTCD TO – PH 2)

This document presented an overview of NASA's SSC, in Hancock County, Mississippi and was submitted to EMD on June 13, 2011. More specifically, this document intended to present the reader with preliminary information regarding the ongoing environmental remediation of contaminated groundwater at SSC using P&T technology.

NASA EMD requested that ITB prepare this summary report as a first step in the analytical process to determine if SSC's P&T strategy is effectively addressing contaminated groundwater and bringing SSC closer to regulatory closure by meeting applicable or relevant and appropriate requirements (ARARs). Information presented in the SSC Summary Report was also to be used in preparation of an upcoming Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) 5-year review.

This 39-page report was developed using data and base maps provided by SSC. ITB reduced laboratory analytical data provided by SSC into more easily interpreted tables summarizing the average contaminant concentrations seen in monitoring wells over the last five years, charts illustrating the historical trends of influent contaminant concentrations to the pump and treat facilities (PTFs), and maps depicting the average groundwater flow directions and the locations of suspected DNAPL TCE. Significant opportunities to improve upon the current cleanup strategies employed at SSC were identified as a result of this report. It was subsequently distributed to the SSC RPM who stated "this is exactly what we were looking for and confirmed what we suspected as well." On July 15, 2011, EMD informed ITB that SSC requested further support in the form of the development of a "mini Feasibility Study to look at what remediation technologies would be best to use given the data we have."

See the SSC Summary, Appendix 4a - Appendix A - SSC Summary Reportv1.pdf

SSC mini-Feasibility Study – ISCO at Area B (as part of RTCD PH2)

EN Rx's August 4, 2011 proposal entailed a pilot-scale application of their ISCO technology at SSC's heavily TCE-impacted Area B. ITB successfully leveraged the proposed donation of in-kind services and equipment and over a 50% discounted cost for ISCO chemical in exchange for exposure and experience at a NASA facility. Even at the reduced rate, it was unlikely that SSC would be able to fund this pilot test while continuing to operate four Pump and Treat Facilities (PTFs). During the September 1, 2011 teleconference, EMD mentioned a possible means to obtain funding by shutting down a PTF and using those operation and maintenance (O&M) funds to pay for the pilot test. ITB subsequently presented this option to EN Rx. Part of EN Rx's remediation strategy was to continue the operation of the PTF during the pilot test to provide additional source removal and hydraulic control. Therefore, the PTF in the area where the pilot test was proposed could not be shut down. As a solution, EN Rx proposed to conduct a full-scale remediation in an area with less contaminant mass that could be more quickly and easily be treated while Area B PTF was shut down.

To recap, ITB successfully leveraged the proposed donation of in-kind services and equipment and over a 50% discounted cost for ISCO chemical in exchange for En Rx receiving exposure and experience at a NASA facility.

MAF – Thermal Remediation Opportunities and Evaluation of ISTD (initiated during PH2)

During the October 25, 2011 teleconference with EMD, ITB was asked to review the final report of in-situ thermal desorption (ISTD) pilot-testing that was recently completed at MAF and provide an unbiased opinion of the results.

ITB was also asked during the teleconference to investigate the potential for settlement of the subsurface to cause building damage during full-scale ISTD at MAF. Research conducted by ITB on this subject did not reveal specific cases where settlement had occurred due to ISTD. However, the following text, obtained from page 31 of EPA's March 2004 document entitled In-Situ Thermal of Chlorinated Solvents: Fundamentals and Field Applications (EPA 542-R-04-010), indicated that soils can shrink and crack at the high temperatures created by thermal conductive heating (TCH), the type of heating proposed for MAF.

> *Soil thermal conductivities are affected by moisture content, with conductivities diminishing as water content decreases. Therefore, once soils become dry, higher temperature gradients are needed to transfer the required energy. Other soil properties, such as permeability, carbon content, grain size, and mineralogy can vary between soils and these properties may, to a lesser extent, affect the well spacing and temperature needed for effective treatment. At high temperatures, soils can shrink and crack …*

This effect was observed first-hand by ITB during our site visit to MAF in April 2012. The surface of a concrete-paved parking lot had collapsed and cracked due to the shrinkage of underlying soils caused by an ISTD pilot-test. The total displacement was approximately two feet of depth at some locations. Based on EPA's statement and ITB's first hand observations, this risk of structure settlement from heated soils located in close proximity to building foundations and infrastructure at MAF should be considered during the design of future ISTD systems. Additionally, ISTD will likely elevate the potential for vapor intrusion of toxic chemicals into occupied structures. (***See the ITB/MAF Trip Report – Appendix 4I***).

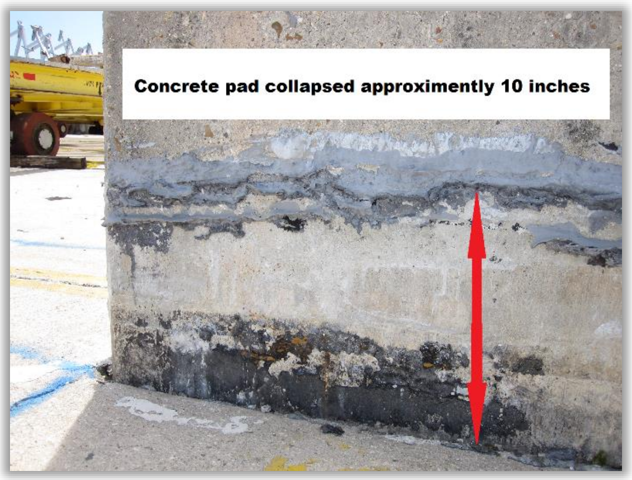

Figure 18 Close-up of parking lot light pole pedestal - MAF

As a result of these findings, ITB questioned whether ISTD is the best remediation strategy for MAF, as suggested by a previous feasibility study.

However, if ISTD was to be continued as the technology of choice to remediate TCE in groundwater at MAF, ITB sought opportunities to reduce its energy costs. One ITB proposed alternative to energy-intensive electrical conductive heating to facilitate thermal desorption of TCE was concentrated solar power (CSP). This technology could be used to heat a fluid and the heated fluid could be circulated through piping installed throughout the subsurface treatment zone.

By converging two technologies:

- Instead of u-tubes that are typical for ground-source heat pump soil thermal coupling, use a pump assisted thermosiphon heat pipe (developed at the U. of Utah) which has superior heat transfer characteristics.
- Use concentrated solar collectors to produce 400deg+ F hot fluid that can be circulated into closed loop in-well pipes (like used for ground source heat pumps) for heat transfer to the surroundings for thermal conduction TCE remediation system use.

During teleconferences conducted in September of 2011, the U.S. Environmental Protection Agency (EPA) Ground Water Ecosystems Restoration (GWER) division (Ms. Eva Davis) expressed interest and enthusiasm in partnering with NASA and ITB in this endeavor.

- Dr. Davis is a hydrologist in GWERD's Applied Research and Technical Support Branch (Ada, OK).
- Since joining EPA in 1990, her work has focused on thermal remediation technologies and the effects of temperature on the properties of organic contaminants and their transport in the subsurface.
- Dr. Davis's current laboratory work includes treatability studies of thermal remediation for contaminants such as creosote and chlorobenzene/DDT.
- Field based research activities include the use of steam injection for the remediation of dense nonaqueous-phase liquids from fractured rock, and a detailed assessment of electrical resistance heating to remediate solvents from tight soils.
- Dr. Davis has also done extensive site-specific technical support for sites where thermal remediation is being considered or is currently being used. Her technical support activities include characterization for remediation purposes; evaluation of the applicability of thermal methods for a particular site; overview of design, construction, and operation; and performance assessments.

The lead subject matter expert for ITB's CSP-supported ISTD concept, Dr. Kent Udell of the University of Utah, was first contacted in the early part of 2011 and he expressed his interest for developing the convergence of these technologies.

- Dr. Udell had previously conducted extensive research and field demonstrations of thermal "heat tube" technology to transfer heat to and from the subsurface.
- He was a professor of Mechanical Engineering at UC - Berkeley when he led the way with developing the steam injection technology for remediation.
- He is currently the Director of the Sustainability Research Center at the University of Utah.

In addition, Dr. Udell began the initial energy balance calculations to establish basic constraints on what can be accomplished using CSP for the thermal remediation applications.

Discussions with Dr. Udell and Dr. Davis presented that, generally, geothermal energy is not hot enough (max temperature of ~ 160F) for remediation purposes, without going to great depths to get the energy needed - in the range of thousands of feet - unless of course there happens to be a very good geothermal system nearby. In addition, Dr. Udell conceptualized a process for renewable energy-supported remediation systems that use modified solar energy systems (e.g. advanced solar water heaters) as steam generators.

- The easiest was to get energy into permeable soils is by steam injection.
- The next is by heating a pipe in the moist soil to a temperature above 120 C (248 F).
- Under the right conditions, the water outside of the pipe will vaporize and flow to an adjacent cooler soil where it will condense, enhancing heat transfer.
- If water returns by capillary action, that enhancement is called the heat pipe effect.

ITB proposed an alternative approach towards using concentrated solar collectors to produce 400deg + hot fluid that can be circulated into closed loop in well pipes (like used for ground source heat pumps) for heat transfer to the surroundings for thermal conduction TCE remediation system use. While concentrating solar collectors can reach higher temperatures than flat plate collectors, the need for a sun tracking system would need to be tested. To overcome the sun tracking concern, ITB identified a new technology from Nanogen that can achieve temperatures to the 600 to 700 degrees (F) range.

Another method for thermal remediation is electrical resistance (ER) in situ thermal desorption (ISTD), or “ERD.” On November 15, 2012, ITB attended a tour of an ERD remediation project in Orlando, Florida hosted by ARCADIS. The tour was very informative and presented potential solutions to MAF’s subsidence issues as well as a technology to regenerate granulated activated carbon (GAC) on site. The findings of this tour were transmitted to NASA by email on November 29, 2012, an overview is in the graphic below.

	Conductive (MAF)	**Resistive (Orlando)**
Cost	$2M	$3M
System power	377 kW	600 kW
Total power used	1,256,089 kWh (139 days)	2,592,000 kWh (180 days)
Air treatment	Thermal Oxidizer + Acid scrubber	Onsite GAC regeneration
Mass Removed	1,150 lbs	7,000 lbs
Volume treated	2,500 cubic yards	22,183 cubic yards
DNAPL treated	Unknown?	Yes
Subsurface dried	Yes	No

This type of heating (resistive- “ERD”) seems to be much better than the conductive heating that MAF pilot-tested. The most interesting information to MAF might be that ERD involves the injection of the extracted/treated water back into the treatment zone to keep the conductivity high. The soil is not dried out and therefore, it’s not likely to shrink and subside. Another interesting feature of the ERD system in Orlando was the onsite granulated activated carbon (GAC) regeneration, which could potentially be more cost-effective than thermal oxidation.

Figure 19 Cost comparison between conductive and resistive heating

Additional Reports & Papers

- National Academies of Science (NAS) Presentation
  - Assisted the ECR Manager (NASA HQ/EMD) in developing a presentation to the NAS; NASA Perspectives on Fractured Rock.
- MAF ISTD Pilot Study Report to NASA EMD/ECR

- ITB has reviewed the NASA Michoud Assembly Facility AOC D (RWA-2) In-Situ Thermal Desorption Pilot Study MO-2 Evaluation Report (prepared by Great Southern Engineering, Inc.) and ITB's site visit trip report presented a brief overview of the project and included findings, comments, and recommendations (***see Appendix 4l***).

- NASA-Wide Fact Sheet on TCE (with Focus Group)
  - Per request by EMD; assisted FOCUS GROUP with the preparation of a fact sheet that elaborates on NASA's efforts regarding TCE—pursuing cleanup, technologies, etc.
- SSC ISCO "one-pager" project overview document (per request from EMD)
  - Project Profile: In Situ Chemical Oxidation (ISCO) – ***See Appendix 4a Project Profile - ISCO v3.pdf***

8. RPM Workshops

Purpose and Approach

Workshops offer value to NASA by providing opportunities for existing and prospective domestic and international project team members to meet face-to-face with NASA to review project status, learn about new environmentally-driven risks and potential solutions, and look for opportunities to develop new joint projects.

ITB has a significant amount of experience with identifying potential speakers for presentations at workshops and conferences. For example, each year, NASA and Center for Portuguese Pollution Prevention (C3P) hosts a technical workshop to discuss ongoing environmental and energy projects and successful technologies. ITB coordinates much of the planning for these workshops, recent of which was held during November 2011, in Noordwijk, Netherlands and which included a session on environmental remediation.

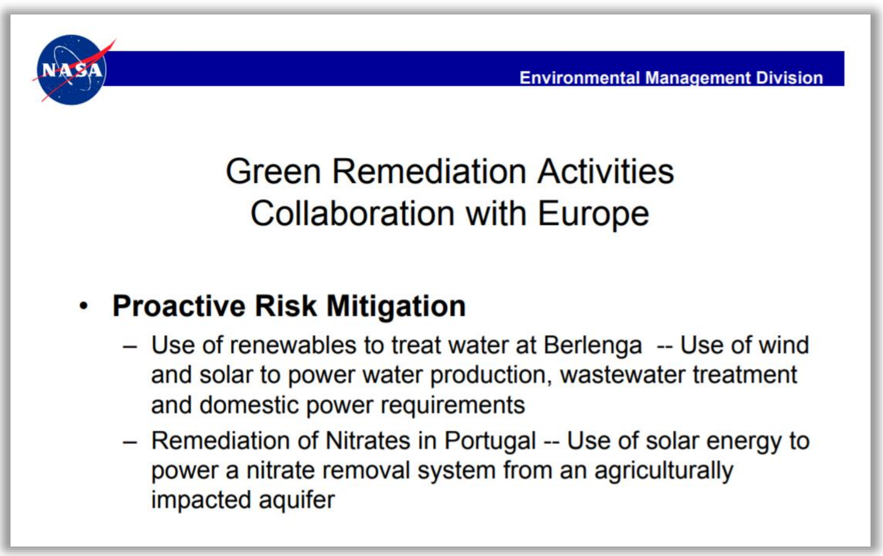

Figure 20 NASA and the C3P collaborate on Green & Sustainable Remediation

The approach for selecting presentation topics and speakers for the NASA RPM Workshops follows ITB's successful methods of, 1) identifying technical subject areas that are engaging and informative, 2) that are applicable to the Agencies' existing clean-up sites and/or, 3) provide insight on emerging areas that are of high interest.

Locations and Speakers

- Huntsville, AL (February 28th – March 3rd, 2011)

As part of the Phase 2 activities, ITB attended NASA's RPM Workshop in Huntsville, Alabama from March 1st through March 3rd, 2011. During the Workshop, RPMs from SSC expressed their need for assistance from ITB in determining the best course of action to take with regard to their upcoming 5-year remediation status review. Additionally, SSC RPMs expressed their concern regarding aging and obsolete pump and treat (P&T) groundwater treatment systems. As a result, SSC was added to the list of Centers and CFs that ITB would focus on during the first 60 days of Phase 2. Other achievements include:

- ITB successfully established relationships with the RPMs who manage remediation projects at the sites recommended within the Phase 1 Final Report (MAF, SSFL and WSTF) and other sites as well.
- ITB continued to develop relationships with other RPMs as considered appropriate in evaluating emerging and alternative remediation technologies.

- LaRC E&E Conference (Tentatively scheduled for May 2012 – Event canceled)

ITB supported NASA EMD in its planning for the 2012 NASA Environment and Energy Conference that was planned for May at Langley Research Center, Virginia. ITB identified and contacted potential speakers for the conference's restoration session(s). In order to benefit a majority of the Restoration Project Managers across NASA, ITB invited a mix of NASA and non-NASA speakers. Ideally, the non-NASA speakers were from across industry and other federal agencies.

NOTE: this event was canceled due to budgetary issues (Sequestration).

Speaker	Organization	Topic
Dr. Fred Aminzadeh	Research Professor at USC, School of Engineering	Modeling and Characterization of SSFL
Dr. Lee Slater	Professor, Graduate Program Director at Rutgers University	Demonstration of a Fractured Rock Geophysical Toolbox for Characterization and Monitoring of DNAPL Biodegradation in Fractured Rock Aquifers (ESTCP Project ER-201118)
Randy Robinson	Badger Injection Solutions	Deployment of Badger Technology for EZVI Injection Delivery
Naji Akladiss	ITRC Integrated DNAPL Site Strategy (IDSS) Team (Team Leader)	Integrated DNAPL Site Strategy
Dave Becker	US Army Corps of Engineers	What is a Remediation System Evaluation (RSE)?
Tim Miller	ABSMaterials	ABSMaterials Pilot Proposal- NASA Stennis Space Center Clean Up AREA B
Dr. Jun Xu	Chemical Sciences Division, Oak Ridge National Laboratory	NASA SSC Field Test of Membrane-Extraction Ion-Mobility Groundwater Monitor
Kent Stewart Udell	Professor and Director of the Sustainability Research Center at the University of Utah	In-Situ Thermal Remediation of DNAPLs using pump assisted thermosiphon technology and concentrating solar power (CSP)
Lance Robinson	EN Rx	Implementation of In-Situ Chemical Oxidation of Trichloroethylene (TCE) in Groundwater for the John C. Stennis Space Center (Area G)
Other considerations:		
KSC's Ground Support Development and Operations (GSDO, previously known as the 21st Century Launch Complex) project at LC-39		
KSC's ESTCP project (Not yet approved)		

Figure 21 Proposed Speakers & Topics - LaRC RPM Workshop

- NASA Remediation Project Manager (RPM) Workshop - February 25 -28, 2013, at Kennedy Space Center (see speaker list; submitted and attended)

Topic	Speaker	Presented
A Case for High-Resolution Pre-Design Investigations Prior to Remedy Implementation	Eric Killenbeck ARCADIS	Y
Innovative ISCO technique to enhance current remediation efforts at SSC	Lance Robinson, P.E EN Rx	Y
Electrical Resistivity and Induced Polarization Geophysics for Non Invasive High Resolution Characterization of DNAPL Distribution Orlando Highlands ERH project	Boyce Clark, Ph.D. ARCADIS	N
Subsurface delivery/distribution of EZVI via a Kinetically Adjustable Porespace Dilation System	Randy Robinson Badger Injection Solutions	N
A New Paradigm for CVOC Contaminant Fate &Transport in Fractured Porous Bedrock (This project approach led to a USEPA approved Technical Impracticability (TI) Waiver and a Record of Decision that stipulated Long-Term Monitoring.)	Daniel J. St. Germain ARCADIS	Y
Horizontal Remediation Wells for Improved Site Cleanup	John Collins, Ph.D. Directional Technologies	Y

Figure 22 RPM Speakers & Topics - KSC RPM Workshop

- JSC, TX RPM Workshop - Speakers and Topic List for the 2015 RPM Workshop

  The 2015 NASA Remedial Project Manager workshop provided an excellent opportunity for ITB staff to meet and network with nearly all of NASA's remediation managers, and to formally present on projects and topics co-developed from the RTCD task order e.g. several pilot projects at Stennis Space Center (SSC), Hyperspectral Imaging for Environmental Assessments and the new ECR Technologies Module in NETS.

  ITB provided/coordinated the guest speakers and topics for presentation:

  - Enhanced Remediation Pilot Study and Performance Based Remediation proposal (SSC/Lance Robinson - En Rx)
  - Hyperspectral Imaging (Amy Keith – Marshall Space Flight Center)
  - Green and Sustainable Remediation – Overview and drivers (Rebecca C. Daprato – Geosyntec)
  - Green and Sustainable Remediation – Case Studies (Paul Favara – CH2M-Hill)
  - NETS ECR Technologies Module Demonstration - DB Consulting Group with ITB (Joe Homan and Wade Olsen)

  The last session, presented by Rebecca Daprato of Geosyntec on Wednesday, was an interactive team-building exercise where the group engaged in a simple evaluation at some "fictional" clean-up sites. The attendees were divided into teams and asked to do a GSR evaluation on a given site and then present their results to the group. This session was a huge success that was enjoyed by all participants.

ITB successfully renewed partnerships with the key individuals who manage remediation projects throughout the Agency and established a relationship with the new (at the time) RPM for Goddard Space Flight Center/Wallops Flight Facility.

Other Travel Opportunities, Site Visits and Virtual Attendance

These meetings and webinars were extremely valuable to ITB for gaining the insight needed to participate in discussions with the appropriate RPMs.

- RTCD Task Order Kick-off Meeting at NASA HQ, Washington D.C - July 7, 2010

  ITB personnel met with the NASA EMD ECR Manager as well as four EMD Liaisons. The meeting was very productive and resulted in EMD introducing ITB to the Center/CF RPM's and therefore implementing the "Collaboration" element of RTCD.

- Attended the Battelle Conference - The Eighth International Conference on Remediation of Chlorinated and Recalcitrant Compounds, May 21-24, 2012 in Monterey, CA.

  The purpose of attending the Battelle Conference was to gain exposure to the latest trends in bioremediation technologies and networking opportunities with SMEs. Attendance to conferences such as this had proven valuable in the past. For example, three of four speakers that ITB provided for the 2013 NASA RPM Workshop were first identified and engaged at the 2012 Battelle Chlorinated Conference.

- Site visit – MAF and SSC, Apr 25-26, 2012
  - MAF – Explore technology opportunities for sub-slab remediation and vapor intrusion / indoor-air quality
  - SSC – EN Rx Pilot Study (in progress)

- EPA's 2014 Vapor Intrusion Workshop - Webinar

  3/18/14 Webinar – "The Challenges, Need for, & Benefits of Long-Term Stewardship" that focused addressing challenges in investigating, assessing, and mitigating vapor intrusion sites (8 hours).

- 2015 EPA Vapor Intrusion Technical Workshop, March 23-24 - Webinar

  EPA hosted a technical workshop on vapor intrusion entitled, *Long-Term Evidence-Based Protection & Sustainability in Residential, Commercial, and Industrial* Buildings, divided into three workshop sessions.

9. Lessons Learned

The value of collaborative discussions:

Ongoing discussions with EMD generated valuable information and guidance on site-specific technologies and opportunities. This feedback saved precious time on the part of the RPMs and for ITB as well. While some alternative technologies appeared to be beneficial to certain clean-up sites at NASA, specific and intimate knowledge would sometimes say otherwise. Examples of proposed technology ideas and concepts that were rejected during the RTCD task's initial 60-Day period:

Discontinue Project Development Option: Upon direction from NASA, ITB discontinued development of project ideas that did not hold promise for meeting the requirements of the RTCD task order.

- An activated persulfate ISCO product (VeruTEK Technologies, Inc.) was rejected by EMD as a proposed remediation technology for NDMA in groundwater at WSTF because of delivery limitations associated with the bedrock geology as WSTF. However, this technology was later reconsidered to treat unsaturated source soils at WSTF.
- A bioremediation/phytoremediation process to address perchlorate in soil and groundwater (Planteco Environmental Consultants, LLC - SAMNAS®) was rejected by EMD because perchlorate contamination was not a significant concern for NASA (at the time).
- A sulfur-based compound (Planteco Environmental Consultants, LLC – MuniRem) proposed for in-situ treatment of NDMA in groundwater and soil at WSTF was rejected by EMD because of delivery limitations associated with the bedrock geology as WSTF.
- Ferrate as an oxidizer and coagulator for in-situ/ex-situ groundwater treatment (Battelle, Ferratec, LLC, Florida Institute of Technology) was rejected by EMD based on their experience with the unstable and relatively expensive characteristics of ferrate when compared to other oxidizers.
- A pump and treat optimization technology (inVentures Technologies, Inc. - gPRO®HP) was rejected by EMD based on concerns that the injection of gases into the flow stream of a pump and treat system prior to re-injection into the target aquifer could cause excessive biofouling of associated groundwater extraction wells.

Technical and Process related lessons learned (*From 2014):*

- Complete Site Characterization and Updated Conceptual Site Models are required for Successful Remediation.

  During review of NASA's remediation program during the first three years, ITB observed a recurring theme; additional site characterization and updated conceptual site models (CSMs) are required before realistic expectations of remediation effectiveness can be determined. In many cases, remedial actions have failed due to inadequate understanding of the size and location of contaminant sources and its effects on groundwater. ITB had learned that proper, complete, and recent site characterization is just as crucial to site cleanup success as selecting the appropriate remedial technology. In order to respond to this immediate need, ITB turned its focus towards innovative assessment technologies in addition to the continued pursuit of remediation technologies.

- ESTCP at KSC

  ITB attempted to secure demonstration projects funded by the Department of Defense's (DoD) Environmental Security Technology Certification Program (ESTCP) at NASA cleanup sites during 2012. Although NASA test sites were ultimately not chosen, ITB; 1) learned more about the opportunities provided through ESTCP as well as the demonstration site selection process, 2) was introduced to key individuals and potential future project partners from industry and NASA, and 3) was introduced to developing remediation technologies. ITB continued to monitor the technologies and demonstration opportunities that were presented by ESTCP.

Additional Lessons Learned:

- Remediation strategies for older spill sites such as NASA's should always take into account that significant contaminant mass has diffused into low permeability zones and will act as a long term source that is difficult to address.

- The success of in situ technology depends mostly on the effectiveness of delivery (contact with contaminant is required).
- The consensus among experts seems to be that TCE is a particularly difficult contaminant to clean-up (i.e. to drinking water standards) and alternative endpoints to active remediation should be considered (long term monitoring and institutional controls may be required).
- Pump and treat should be considered a containment strategy, not a remediation strategy.

10. Summary and Recommendations

Summary of Accomplishments:

- Risk-Based Closure – the next step for Agency-wide "low hanging fruit" opportunities (on-going)
- Technology Demonstrations and Pilot Studies at SSC
  - Performance-Based Contracting at SSC (on-going)
  - In-situ Real-Time Monitoring of (TCE) in Groundwater
  - In-situ Chemical Oxidation (ISCO) of TCE in Groundwater (on-going)
  - ISCO of Contaminated Soils using Horizontal Direction Drilling (HDD) for Injection
- Real-Time Monitoring, Detection and Mitigation for Vapor Intrusion of TCE (research and development is on-going)
- Ultraviolet (UV) Photochemical Degradation Enhancement (WSTF)
- Sustainable Energy Sources to support remediation technologies (on-going)
- Innovative Site Characterization Technology – Hyperspectral Imaging (Proof of Concept completed successfully, research and development is on-going)
- NETS ECR Technologies Module (on-going)
- Agency-wide Assessment of ICS as it applies to cleanup technologies

Recommendations/Issues/Concerns:

- Continue: Agency-wide analysis of sites where Risk-Based Closure can be an effective alternative
- How to convey the importance of attending conferences and workshops?
  - Successes: Collaborative Partners for pilot studies at NASA were met at conferences etc.
  - Convinced: Attending certain conferences are essential
- New V.I. acute exposure limit to TCE are coming to fruition. Risks associated with TCE vapor intrusion into NASA buildings, particularly at ARC, JPL and MSFC, are confirmed issues. Also, there's a potential cost risk if thresholds are exceeded.
  - May require continuous real time monitoring of indoor air
  - Evacuations of buildings if thresholds are exceeded…
  - Several states including California and New Jersey are following the EPA Region 9's lead and have begun using or are considering developing short term exposure limits for TCE
- Determine/assess the potential effects of catastrophic events on existing clean-up sites

11. Appendix: Referenced Documents

1 - NASA.NNH10AA09D15D.RPT.FinalPhIRTCD.WO.12.28.10.pdf
2 - NASA.NNH11AA22D.RPT.RTCDPh2-60DaySummary.WO.JR.04.04.11.pdf
3 - NASA.NNH11AA22D.RPT.FinalRTCDPh2.JR.WO.12.30.11.pdf
3a - NASA.NNH11AA22D.RPMWrksp.TR.WO.03.11.11.F.pdf
3b - SUMMARY Santa Susana Field Laboratory-v5a.pdf
4 - NASA.NNH12AA38D.RPT.2012FinalRTCD.JR.WO.12.21.12.v4.pdf
4a - Appendix A - SSC Summary Reportv1.pdf
4a - Project Profile - ISCO v3.pdf
4b - Appendix B - EN Rx 14-Dioxane Treatment 90.pdf
4c - Appendix C - NAS001-UpdatedVOCEaterProposal8 24 2012.pdf
4d - Appendix D - NASA-ITB letter of support JR 082812.pdf
4e - Appendix E - Groundswell Demo Summary - NASA (1).pdf
4e - Appendix E - NASA SSFL proposal_08272012.pdf
4f - Appendix F - NESDI GTRI FactSheet_ID-468.pdf
4g - Appendix G - BioStryke ERDenhanced Pilot Study Letter_Proposal v2 ITB Inc Sept 24 2012.pdf
4h - Appendix H - Thermal_TS_Workplan.pdf
4i - Appendix I - Geosyntec - Electrokinetics.pdf
4j - Appendix J - cornell_prap_7-2012.pdf
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5c - 2013 RPM Workshop Speaker Abstracts and Biographies - KSC (V2).pdf
6 - NASA.NNH12AA38D.RPT.RTCD Final Report 2015 wAppen.WO.02.27.15.pdf
7 - NASA NNH15CN32D RPT RTCD Mid-Year Report 2015 WO JR KR v5.pdf
7a - NASA.NNH15CN32D.RPT.FINAL LaRC Remediation Prog Assessment.JR.07.31.15.pdf
7b - A-A SSC COMBO PROPOSAL 152215.pdf
7c - LaRC A-A Restoration site map.JR.07.31.2015.pdf
8 - NASA.NNH15CN32D.RPT.RTCD Final Report 2015.WO v2.02.29.16.pdf
8a - SSC Area B Vertebrae Assessment Report 082914 final.pdf
8b - SSC Area C PBC Proposal 150216.pdf
8c - Area D_Risk Option_122015_PLH.pdf
9 - NASA.NNH15CN32D.RPT.RTCD Final 2016.WO.02.28.17.pdf
9a - Proposed RPM Webinar Topics.10.17.2016.pdf
9b - PBR and PBC at SSC - EN Rx.pdf
9c - DRAFT - Alternative Remediation Technologies for NASA GSFC at Greenbelt.pdf